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FTIR Analyses of Hypervelocity Impact Deposits: DebriSat Tests

March 27, 2015

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14. ABSTRACT
The DebriSat tests were conducted to better understand the distribution of fragments generated from a hypervelocity impact with a modern satellite. The last such test (SOCIT) was conducted 20 years ago and satellite construction has changed considerably since then. DebriSat was a NASA program with support/collaboration from the Air Force Space and Missile Center, University of Florida and Aerospace. It consisted of three tests: Pre Preshot, Debris-LV and DebriSat. Tests were conducted at the Arnold Engineering Development Complex Range G Two-Stage Light Gas Gun Facility with a pressure of 1-2 Torr of air and using ~600 gram projectiles with nominal velocities of 7 km/s. The Pre Preshot target was a multi-shock shield supplied by NASA designed to catch the projectile. It consisted of seven bumper panels consisting of fiberglass, stainless steel mesh and Kevlar. Debris-LV used a 15 kg target fabricated by Aerospace to simulate a spent upper stage. DebriSat consisted of a 50 kg target constructed by the University of Florida from materials representative of a modern LEO satellite.

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Abstract

The DebriSat tests were conducted to better understand the distribution of fragments generated from a hypervelocity impact with a modern satellite. The last such test (SOCIT) was conducted 20 years ago and satellite construction has changed considerably since then. DebriSat was a NASA program with support/collaboration from the Air Force Space and Missile Center, University of Florida and Aerospace. It consisted of three tests: Pre Preshot, Debris-LV and DebriSat. Tests were conducted at the Arnold Engineering Development Complex Range G Two-Stage Light Gas Gun Facility with a pressure of 1-2 Torr of air and using ~600 gram projectiles with nominal velocities of 7 km/s. The Pre Preshot target was a multi-shock shield supplied by NASA designed to catch the projectile. It consisted of seven bumper panels consisting of fiberglass, stainless steel mesh and Kevlar. Debris-LV used a 15 kg target fabricated by Aerospace to simulate a spent upper stage. DebriSat consisted of a 50 kg target constructed by the University of Florida from materials representative of a modern LEO satellite. For both Debris-LV and DebriSat, the test chamber was lined with "soft catch" foam panels to trap fragments for size distribution analysis. Witness plate assemblies were constructed by Aerospace in order to catch and sample debris and returned to Aerospace after the test for analysis. Aerospace also placed SEM stub witness plates into the soft catch panels for post test retrieval and analysis. "Darkening" of satellites has been observed as a result of suspected hypervelocity impacts. The material responsible for the darkening is unknown. Various materials have spectral features in the LWIR that can be used to identify them. LWIR reflectance measurements were made on target and witness plates before and after the impacts in order to characterize the spectral signature of hypervelocity impact debris.

The Pre Preshot test did not utilize soft catch foam and hence had no soft catch contamination. Therefore, of the three tests, it represents the best example of hypervelocity impact debris spectral signatures. Post test spectra showed silicate and borate features from melted/vaporized E-glass from penetrated bumper shields. Darkening to < 25% reflectance was observed on many surfaces after the hypervelocity impact. Soft catch contamination was prevalent on Debris-LV and DebriSat fragments. Soft catch film condensed from vaporized foam was also present on SEM stubs, in addition to soft catch fragments. Spectra from soft catch made it difficult to evaluate the true hypervelocity impact spectral signature. Debris-LV samples did have an extra feature at 800 cm^{-1} possibly due to a form of aluminum oxide which may have come from the LV aluminum tank or projectile. Aluminum oxide was not as evident on DebriSat fragments but there were fewer samples to examine since there was less aluminum in the DebriSat structure. It was observed in witness plate samples. The formation of an oxide would not occur on orbit unless there was a source of oxygen in the impacted materials. Darkening to < 10% reflectance was observed on Debris-LV and DebriSat witness plate surfaces after hypervelocity impact. This was greater than on pre Preshot (to 20-25%) and was possibly due to extra soft catch contamination. However, disordered graphitic carbon also detected on Debris-LV and DebriSat. It has no spectral features but is highly absorbing and may have produced the black "sooty" appearance.

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DebriSat Team Members:

- J.-C. Liou: NASA Space Debris Program Office, NASA JSC
- AEDC Range G Light Gas Gun Staff
- Charles Griffice: Aerospace
- Marlon Sorge: Aerospace

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- Ray Russell
- Rick Rudy

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FTIR Analyses of Hypervelocity Impact Deposits: DebriSat Tests

19 January, 2015

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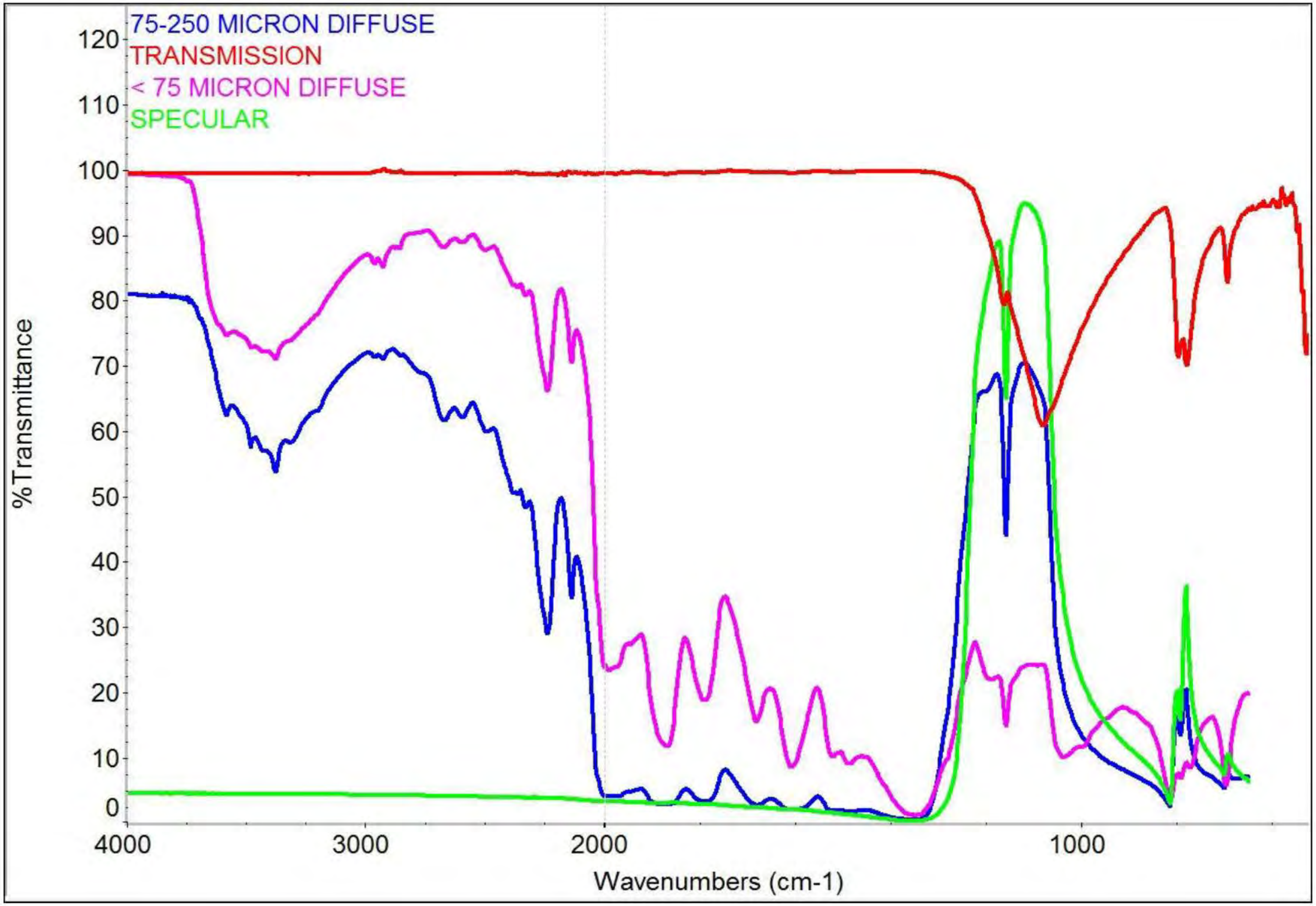
Introduction

- The DebriSat test was conducted to better understand the distribution of fragments generated from a hypervelocity impact with a modern satellite.
  - The last such test (SOCIT) was conducted 20 years ago and satellite construction has changed considerably since then.
  - In 2009 a Cosmos 2251 upper stage collided with an Iridium 33 satellite.
    - 2000+ trackable fragments (>10 cm).
  - 8 known other collisions, some only known long after occurrence.
- DebriSat was a NASA program with support/collaboration from the U. S. Air Force Space and Missile SystemsCenter, Aerospace and University of Florida.
- Tests were conducted at the Arnold Engineering Development Complex, Tullahoma, Tennessee.
  - Two-Stage Light Gas Gun Facility Range G.
  - Largest such facility in the United States.
  - All tests used a ~600 gram projectile with a nominal velocity of 7 km/s.
- Two trial tests were conducted prior to DebriSat.
  - Pre Preshot – February 2014.
  - Debris-LV (Pre Shot) – April 1, 2014.
  - DebriSat - April 15, 2014.

- Background
  - “Darkening” of satellites has been observed as a result of suspected hypervelocity impacts.
  - The material responsible for the darkening is unknown.
  - Many materials have molecular vibrations at long wave infrared (LWIR) wavelengths that can be used in identification and can be observed remotely.
- Objectives
  - Infrared reflectance spectra will be measured of pretest materials used to construct targets.
  - Material collected on target fragments and witness plates in hypervelocity impact tests will be analyzed in order to identify the material responsible for the darkening.
  - Infrared reflectance spectra will be measured of post test debris fragments for comparison with pre test to determine the spectral signature of material generated by a hypervelocity impact.

- Supplemental and supportive information from other analyses have been documented separately. References are given at the end of each section.
  - Scanning electron microscopy (SEM).
  - Transmission electron microscopy (TEM).
  - Energy dispersive X-ray spectroscopy (EDS) in the SEM/TEM.
  - Raman spectroscopy.
  - UV-VIS-NIR spectroscopy.

Comparison of Types of FTIR Spectra (Quartz)

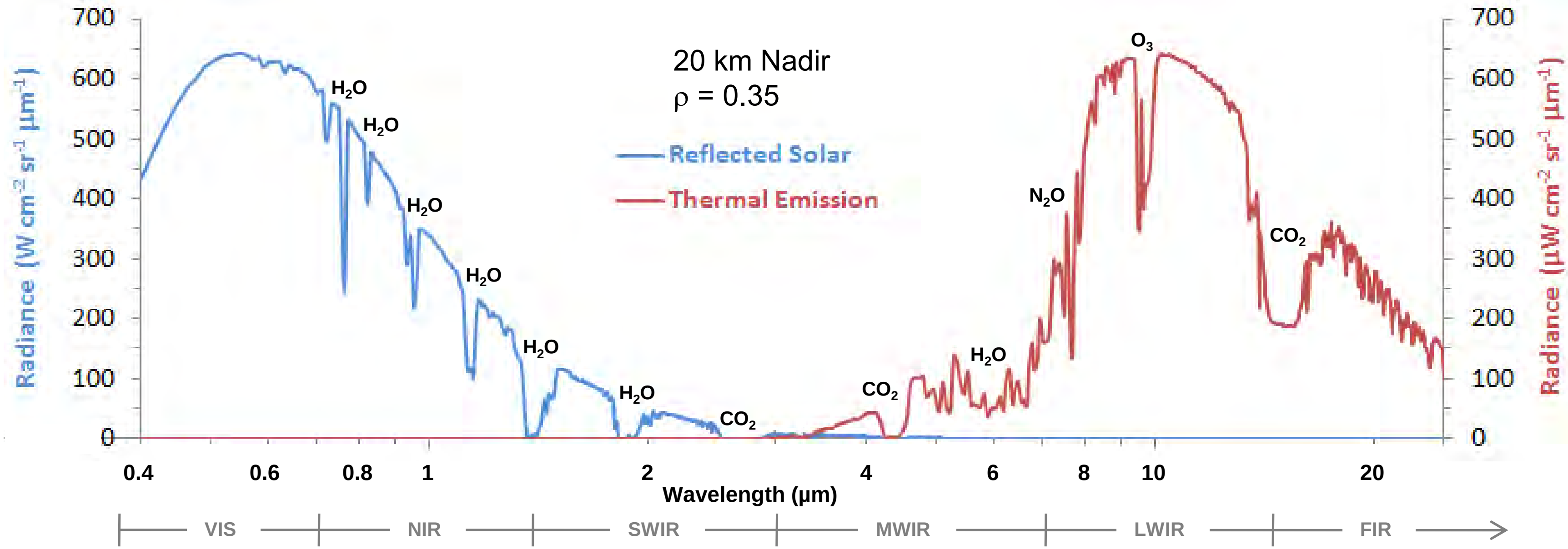


The appearance of an FTIR spectrum of a material can vary dramatically depending on the materials form and how it is measured.

Spectral Interpretation

- Spectral interpretation is not simple.
- Transmission, specular reflectance and diffuse reflectance spectra are different.
  - Molecular vibrations produce transmission minima in transmission spectra (absorption bands).
  - Molecular vibrations produce reflectance maxima in reflectance spectra (reststrahlen bands).
- Diffuse reflectance (biconical, hemispherical) spectra are also particle size dependent.
- There is not a unique spectral signature for a material – it is thickness, surface roughness and particle size dependent.
  - The reflectance spectrum of a thin film of a transmissive material on a reflective substrate will produce a transmission-like spectrum, whereas the bulk material will produce a normal reflectance spectrum.
- Remotely sensing spectra have limited band width because of “atmospheric windows”.
- Remote sensing measures emissivity (E)
  - Related to reflectance (R) by Kirchhoff’s Law: $E=1-R$

Remote Sensing Atmospheric Windows



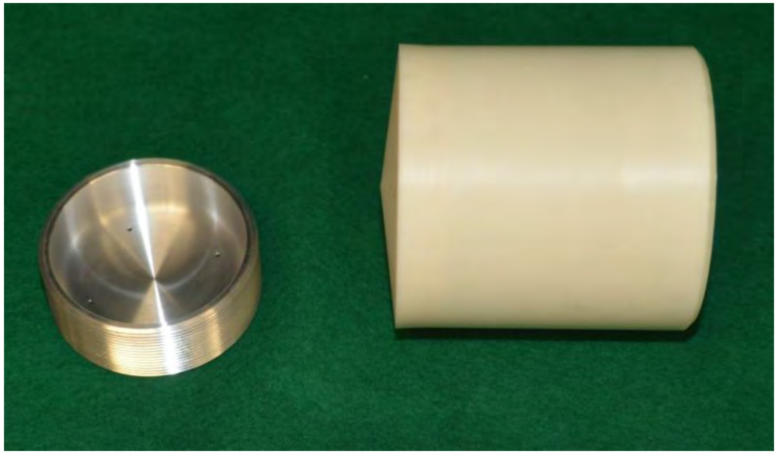
- Atmospheric water vapor and carbon dioxide greatly reduce useable spectral bandwidth.
  - LWIR window is from 8-13 microns (1250-770 cm^{-1}).
- Laboratory reflectance measurements are conducted in a dry nitrogen purged sample compartment.
  - Exoscan portable FTIR is not purged but has only a 2 cm atmospheric path length.

Pre Preshot Test

Introduction

- Conducted February 2014.
- Validated performance of projectile to meet velocity goal of 7 km/s.
- Confirmed operational status of test chamber and facility.
- Target was primarily designed to catch the projectile without damage to the test chamber.
    - Was a multi-shock shield supplied by NASA.
    - Multiple (7) bumper panels of fiberglass fabric (#1,2, 4, 5), stainless steel mesh (#3) and Kevlar (#6,7).
- No “soft catch “ panels were installed in the chamber.
- A witness plate assembly was provided by Aerospace in order to catch and sample debris for later analysis.
- More details given in P. M. Adams and P. M. Sheaffer, DebriSat Pre Preshot Laboratory Analyses, The Aerospace Corporation TOR-2014-03083.

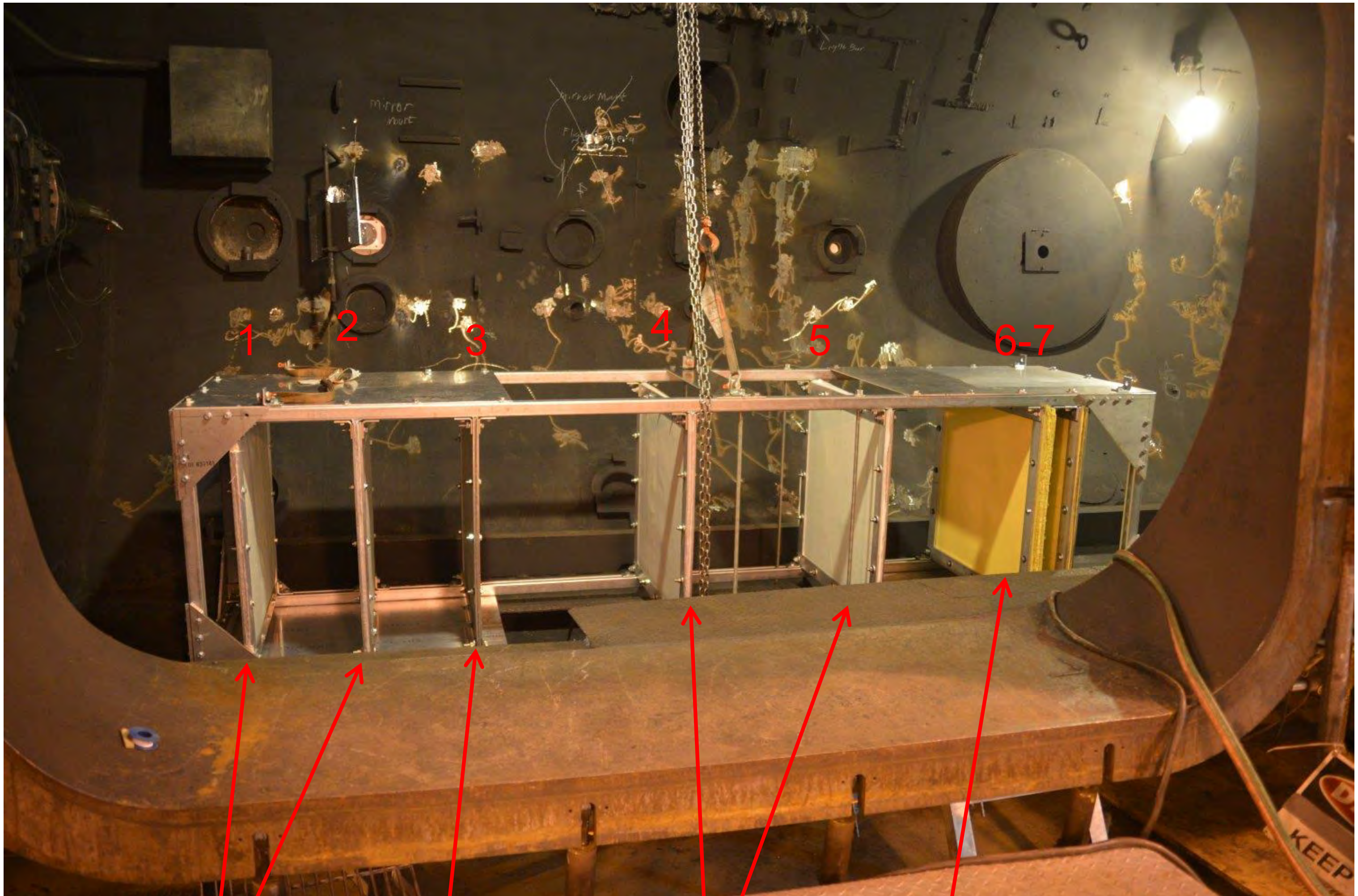
Projectile



Hollow aluminum and Nylon cylinders. Constructed from three pieces: Outer Nylon shell (sabot) with aluminum inserts.
~600 grams, 8.6 cm diameter X 10.3 cm long – size of a “coke can”

Same type of projectile was used for all three tests.

Target being loaded into chamber.



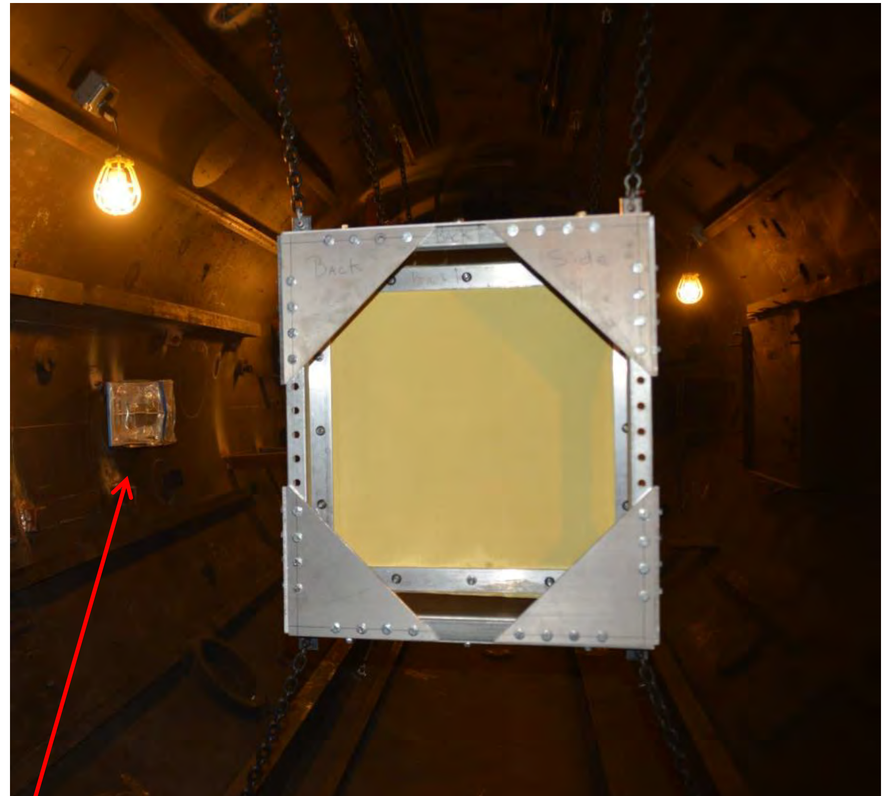
E-glass Steel E-glass Kevlar

Image by AEDC

Overall length of the target was 2.65m. Witness plate assembly was mounted on the side of the chamber between bumpers 3 and 4

Target and Witness Plate in Chamber

Note no soft catch panels present in chamber



Looking Down Range

Fiberglass panel in front.
Witness Plate Covered in Plastic at Right

Witness plates

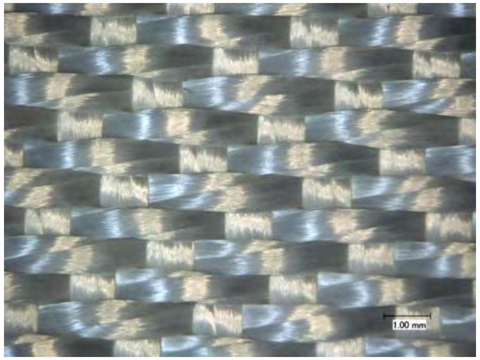
Looking Up Range

Kevlar panel in back.
Witness Plate Covered in Plastic at Left

Images by AEDC

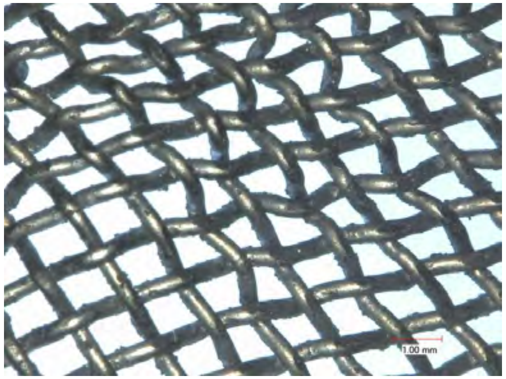
Bumper Materials

- Fiberglass bumpers (#1, 2, 4, 5) constructed from FG-3784 satin weave E-glass fabric
  - 22 layers of 26 oz per sq ft fabric for each bumper
  - ~7 micron fiber diameter
  - E-glass is a calcium boro-aluminosilcate
    - Minor Na, Mg



FG-3784 fabric

- Steel bumpers (#3) constructed from 300 series stainless steel (SS) mesh.
  - Filaments are about 0.4 mm dia.
  - Seven sheets were stacked
  - 69.1 % Fe, 18.2% Cr, 10.8% Ni, 1.4 % Mn, 0.5% Si (wt %)



SS Mesh

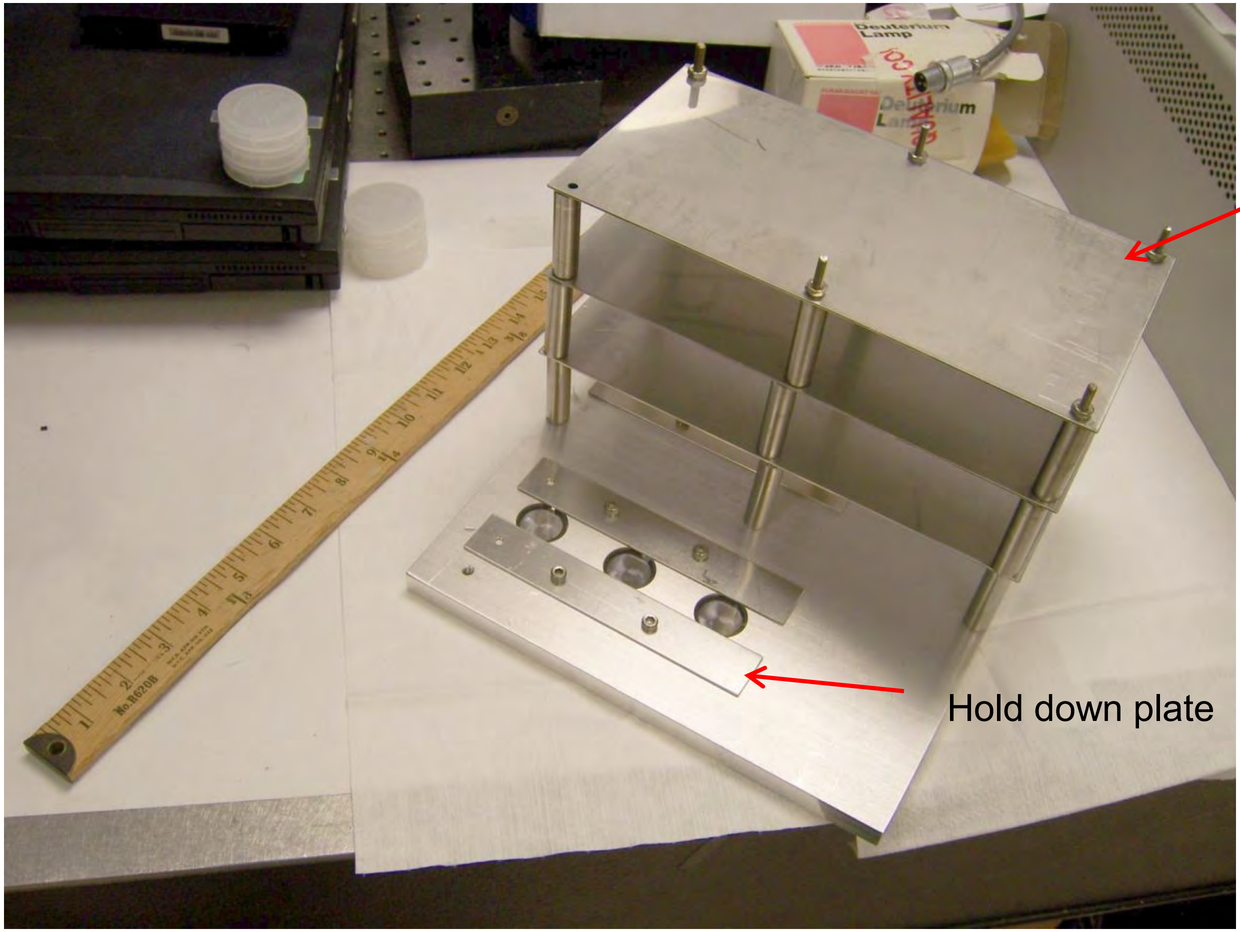
Target - Post Test

Image by AEDC

4^{th} and 5^{th} bumpers dislocated from frame.
No penetration.

First 3 bumpers penetrated

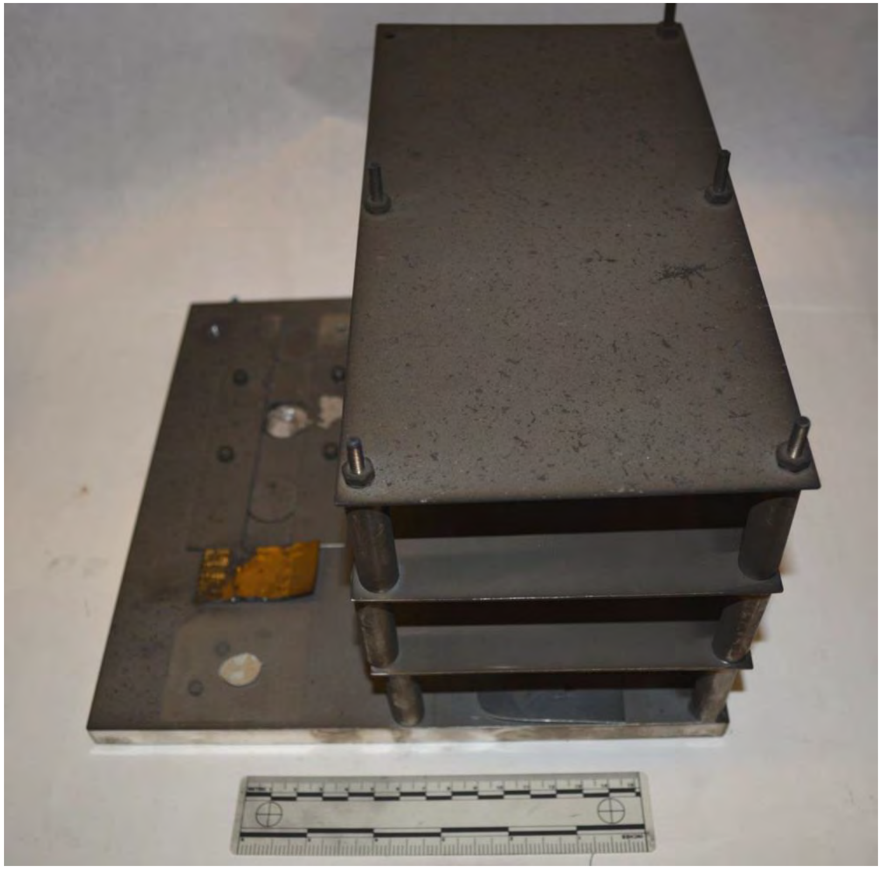
Witness Plate Assembly: Pre Test



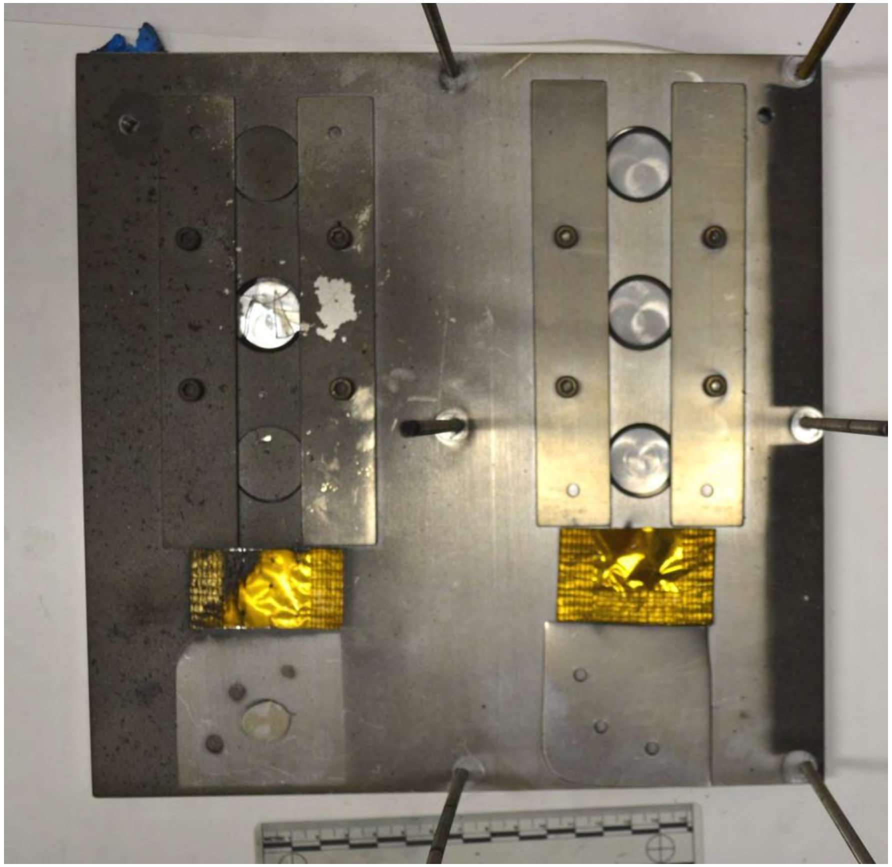
(3) 1” diameter quartz windows – directly exposed and protected under Whipple plates.
Multilayer insulation (MLI) samples added later.

Assembly positioned about 1 meter from center of target on wall of chamber

Witness Plates: Post Test



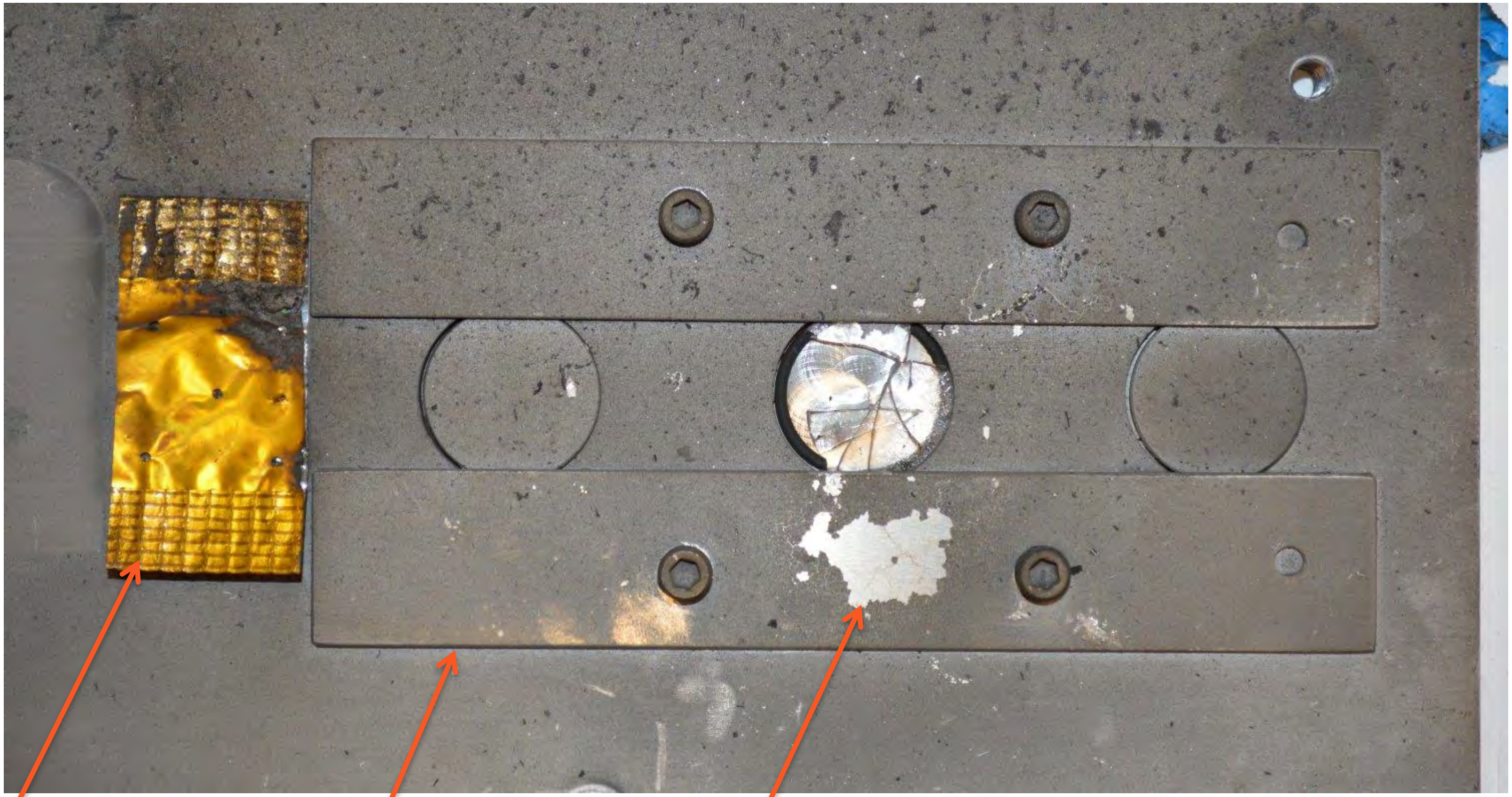
With Whipple plate shields



Whipple plates removed

Exposed surfaces are covered with a matte gray coating and fine debris

Witness Plates: Post Test (unprotected)



Multi layer insulation

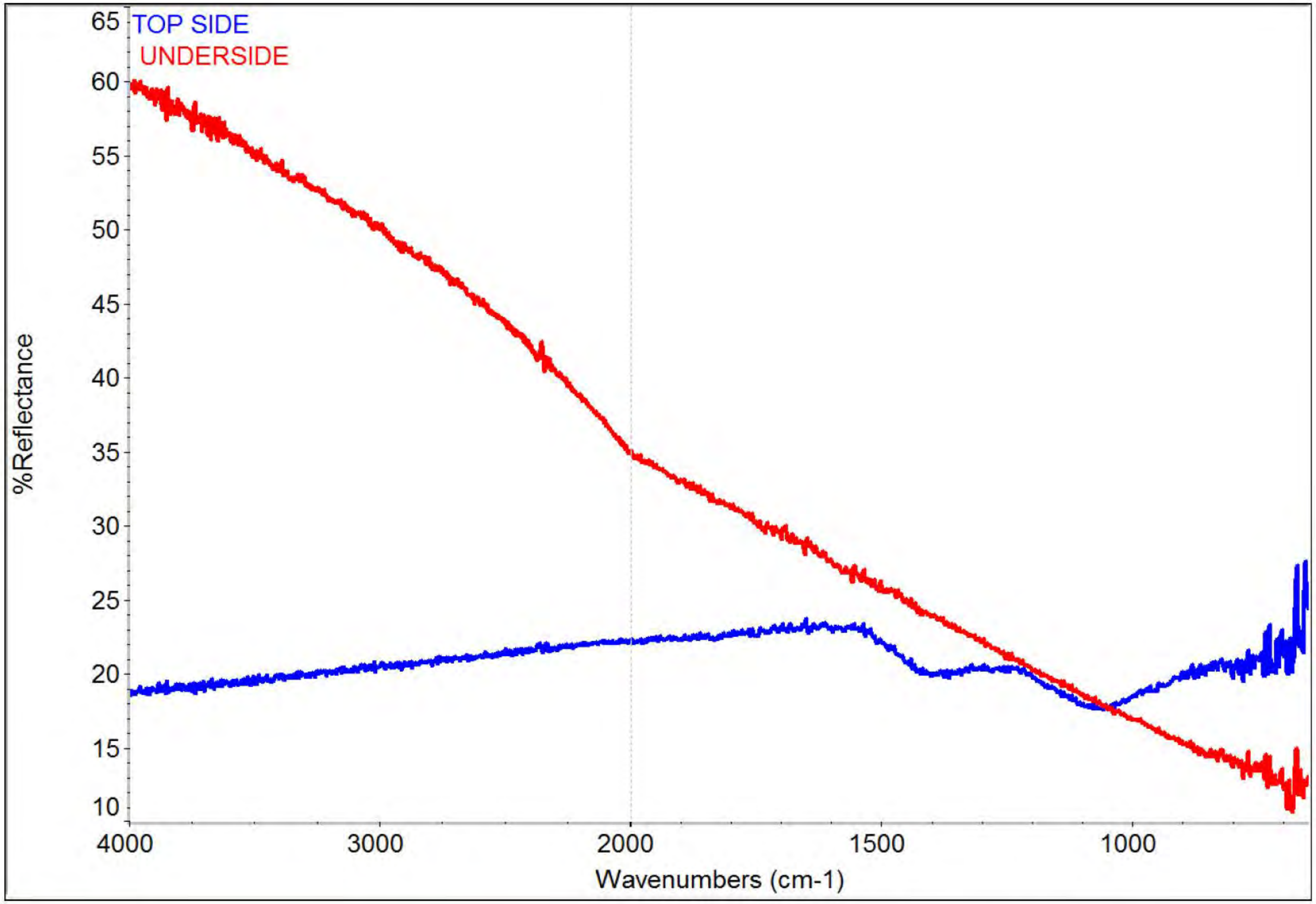
Hold down plate

Note blistered coating flaked off and fractured quartz window

Exposed surfaces are covered with a matte gray coating and fine debris

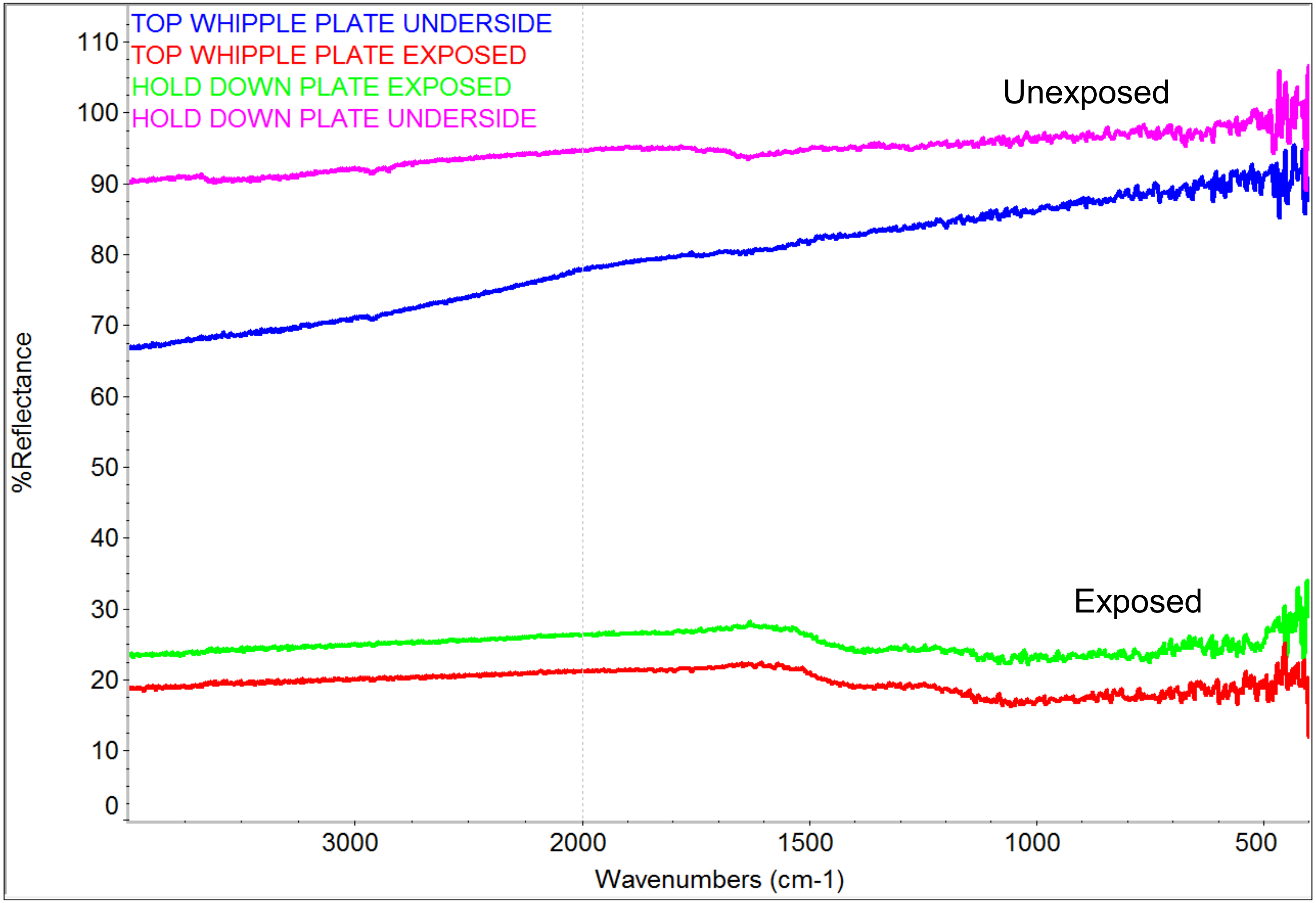
Top Whipple Plate

Exoscan Qualitative Biconical Reflectance



Unexposed stainless steel and uncoated underside of Whipple plate are featureless.
Post test coating has two absorption features.

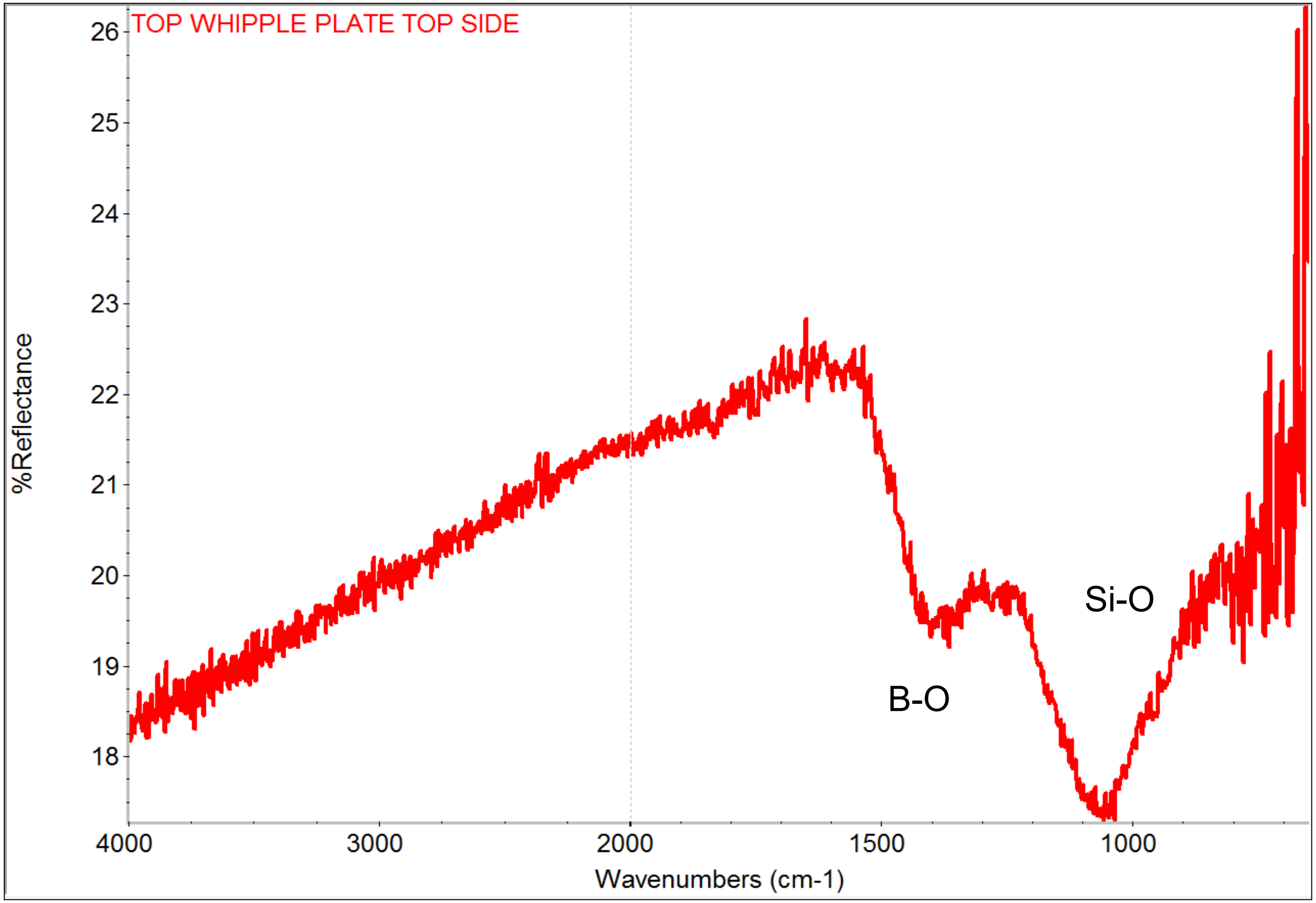
Quantitative FTIR – LWIR Hemispherical Reflectance



Significant decrease in reflectance from 90% to 20% – “darkening”. Note - underside of Whipple plate had a very thin deposit – compare with hold down plate.

Top Whipple Plate
FTIR (post test)

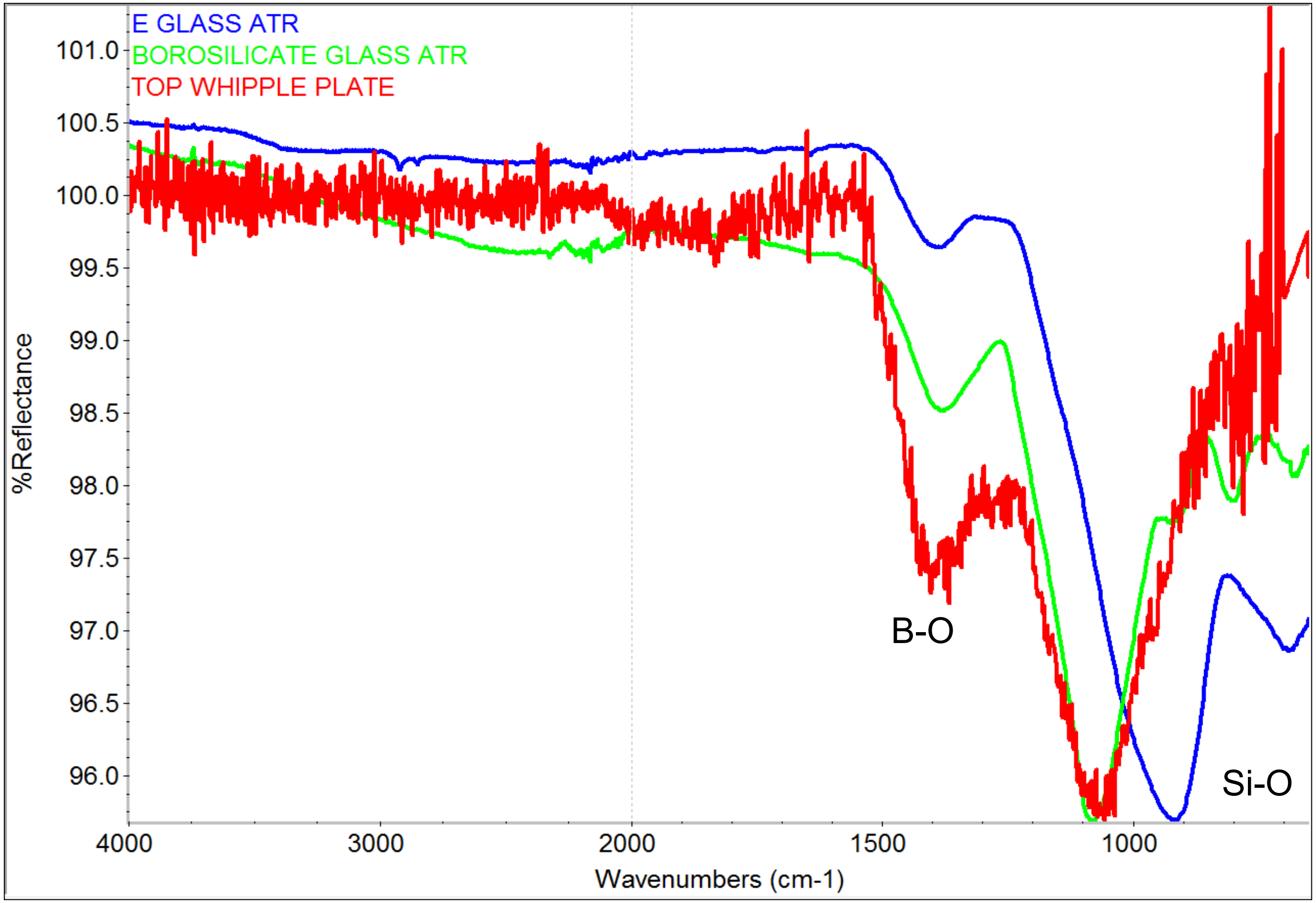
Two reflectance minima occur from transmission through silicate material and reflectance off underlying metal



Feature at 1070 cm^{-1} is from a silicate. Feature at 1400 cm^{-1} is from "borate" in borosilicate.

Infrared Spectra of Silicate Glasses

Attenuated total reflectance (ATR) and diffuse reflectance (Whipple plate)



Silicate peak shifts from 910 cm^{-1} in E-glass to 1070 cm^{-1} implies a change in composition and Si-O bond frequency .

Summary

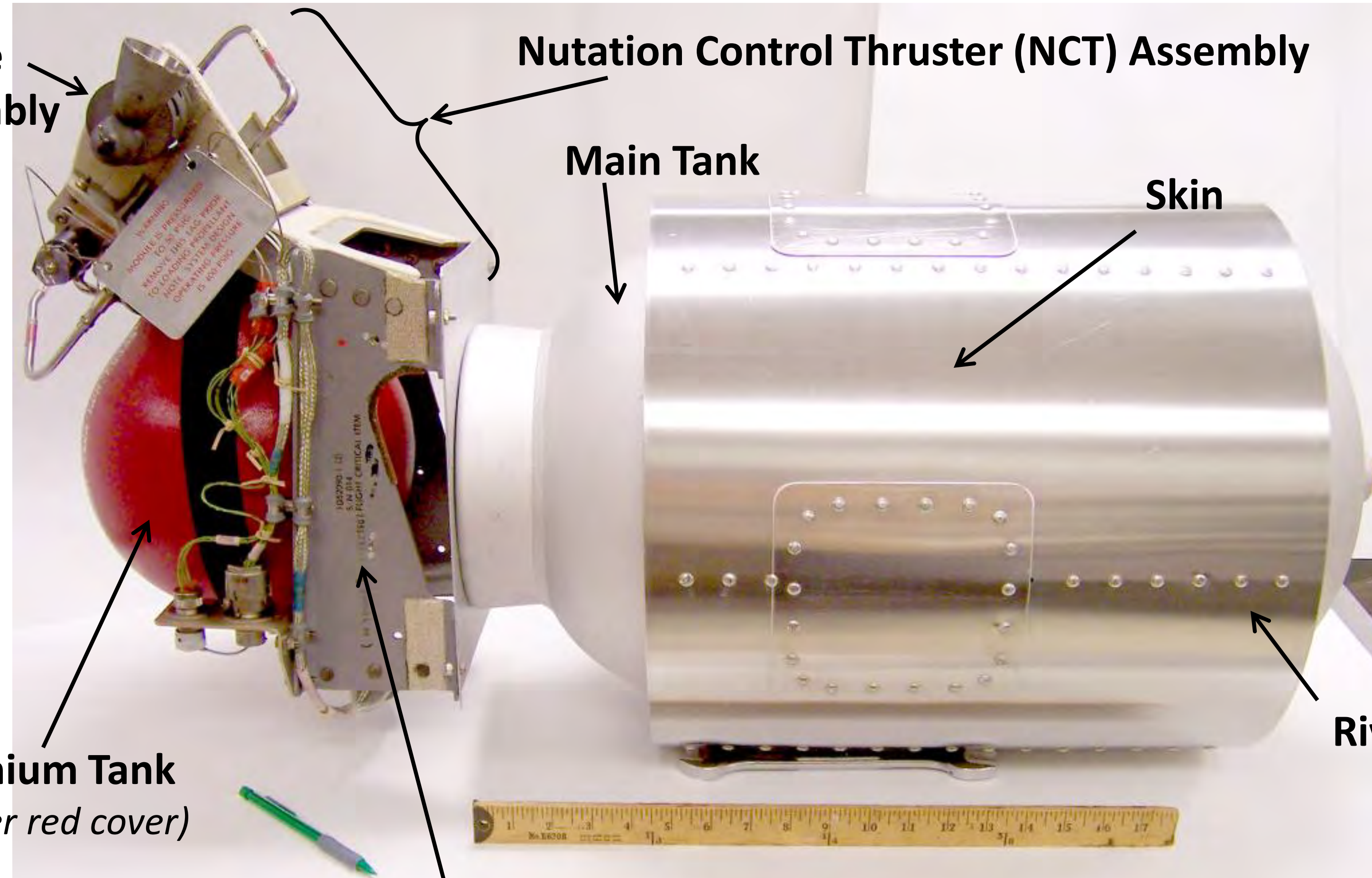
- Significant darkening of witness plate occurred as a result of impact.
  - Drop from 90-95% to 20-25% reflectance.
    - As a result of increased scattering from particulate deposition.
    - Carbon is not present, which has been attributed to darkening on orbit.
    - Deposited material is gray – not black.
- Deposition appears to be line of sight.
- LWIR spectral features are related to silicate and borate from the E-glass bumpers that were penetrated.
  - Silicate feature shifts as a result of change in stoichiometry.
- SEM and EDS showed that the E-glass along with the stainless steel was melted and/or vaporized and deposited on the witness plate about 3-4 feet away from point of impact.
  - P. M. Adams and P. M. Sheaffer, DebriSat Pre Preshot Laboratory Analyses, The Aerospace Corporation TOR-2014-03083.

Debris-LV Test

Background

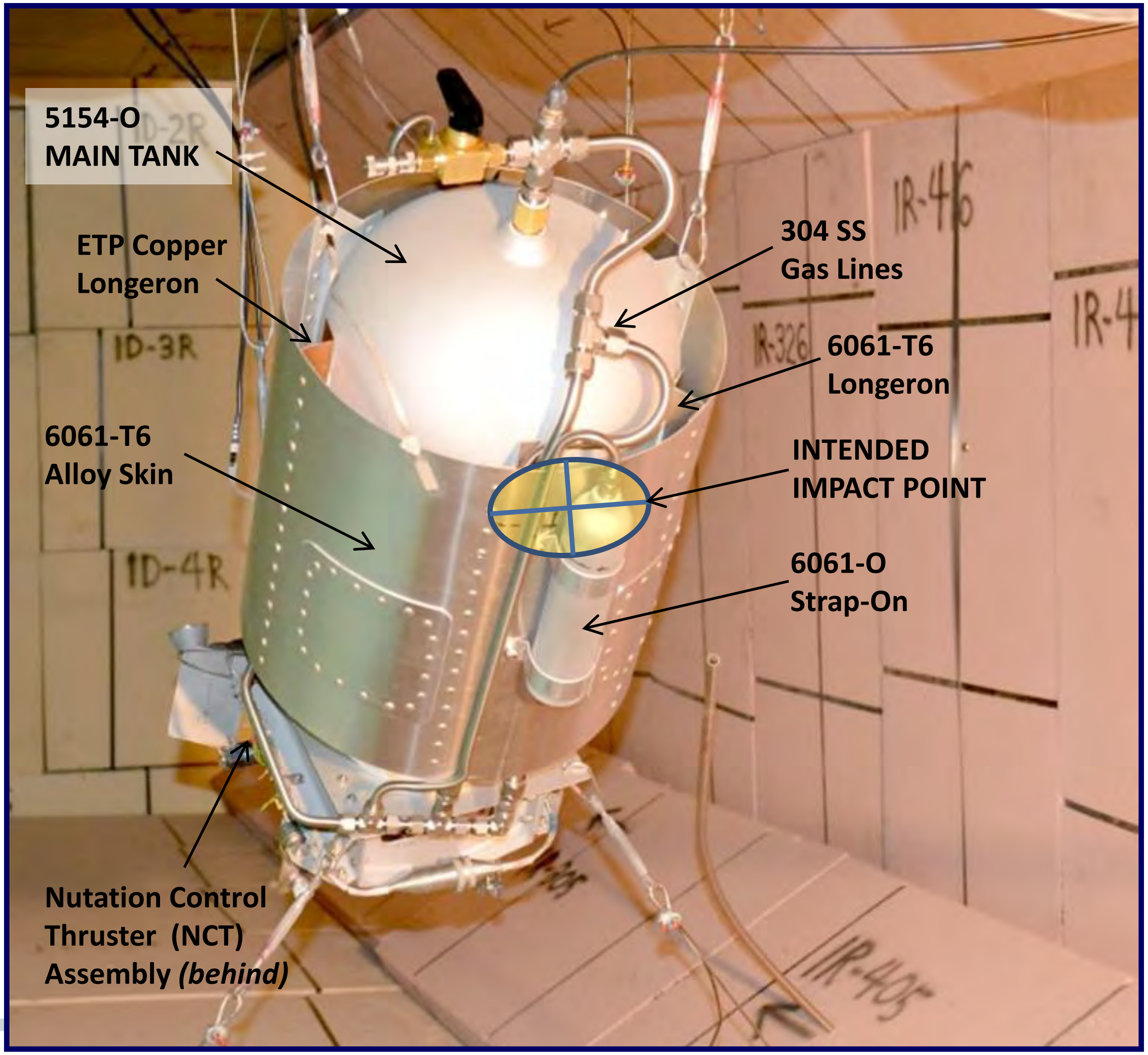
- Conducted1 April 2014.
- Further validated performance of projectile and facility and served as a dress rehearsal for the DebriSat test.
- The 15 kg target consisted primarily of empty tanks and was constructed by Patti Sheaffer from materials representative of a launch vehicle (LV) upper stage.
  - Primarily aluminum and titanium with lesser amounts of copper and stainless steel.
- Test chamber was lined with “soft catch” foam panels to trap fragments for size distribution analysis.
- A witness plate assembly was constructed by Aerospace in order to catch and sample debris and returned to Aerospace after the test for analysis.
- Aerospace also placed SEM stub witness plates into soft catch for post test retrieval and analysis.
- Additional information in P.M. Adams, P. M. Sheaffer, Z. R. Lingley and G. Radhakrishnan, Debris-LV Laboratory Analyses, The Aerospace Corporation TOR-2015-00928.

Debris-LV prior to delivery



Main tank and skin are aluminum

Debris-LV in test chamber



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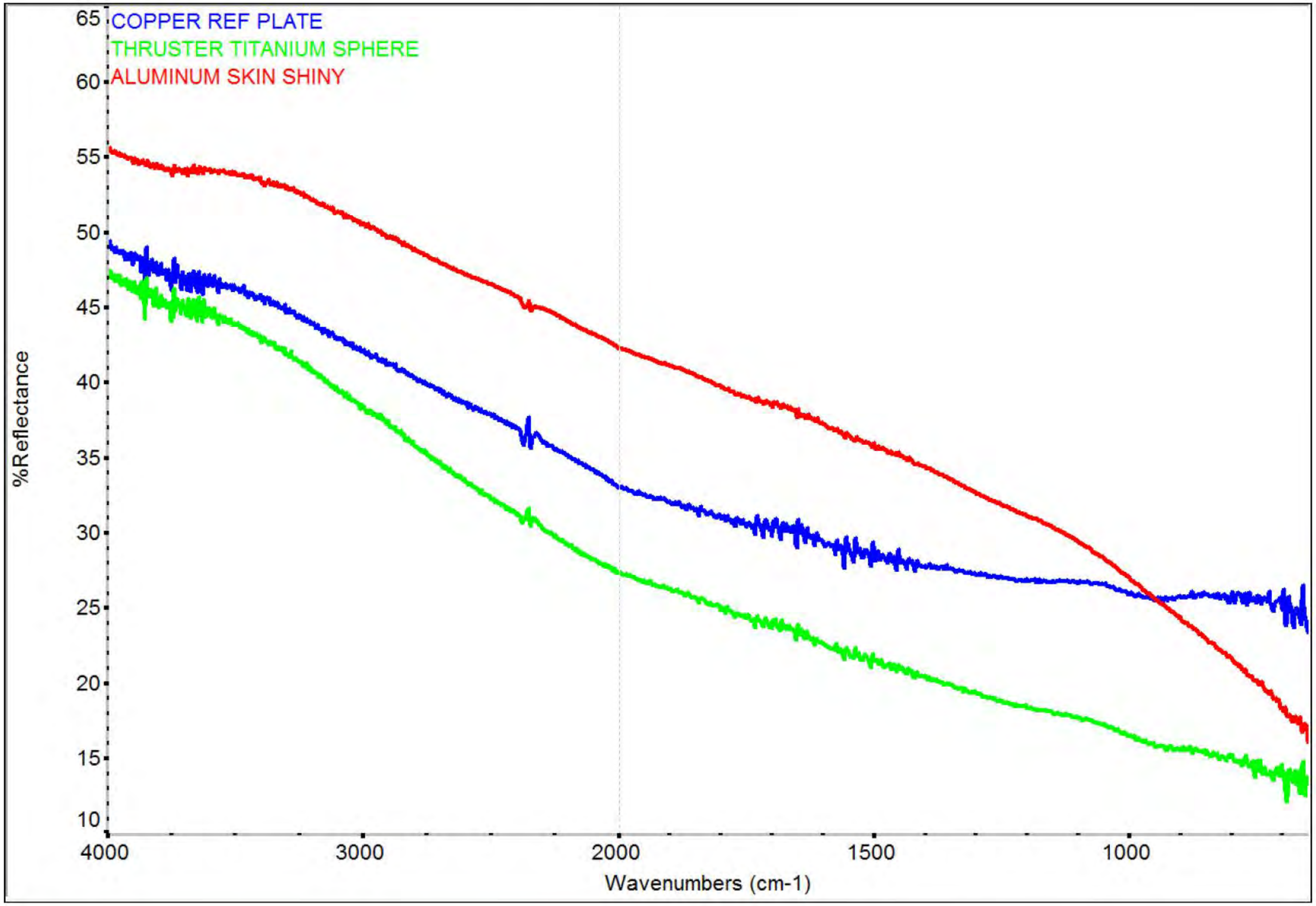
Samples Analyzed

- Representative materials on exposed Debris-LV surfaces.
  - With Exoscan portable FTIR: Pre test surfaces and post test fragments.
- Additional materials on witness plate assembly.
  - Multi layer insulation (MLI) , solar cell, Z-93 thermal control paint, aluminum.
  - Laboratory biconical and hemispherical reflectance: pre and post test.
- SEM stub witness plates placed on soft catch.
  - Biconical reflectance: Unexposed and exposed.
- Samples from “soft catch” panel thermal decomposition test.
  - By attenuated total reflectance (ATR) or transmission for material identification.

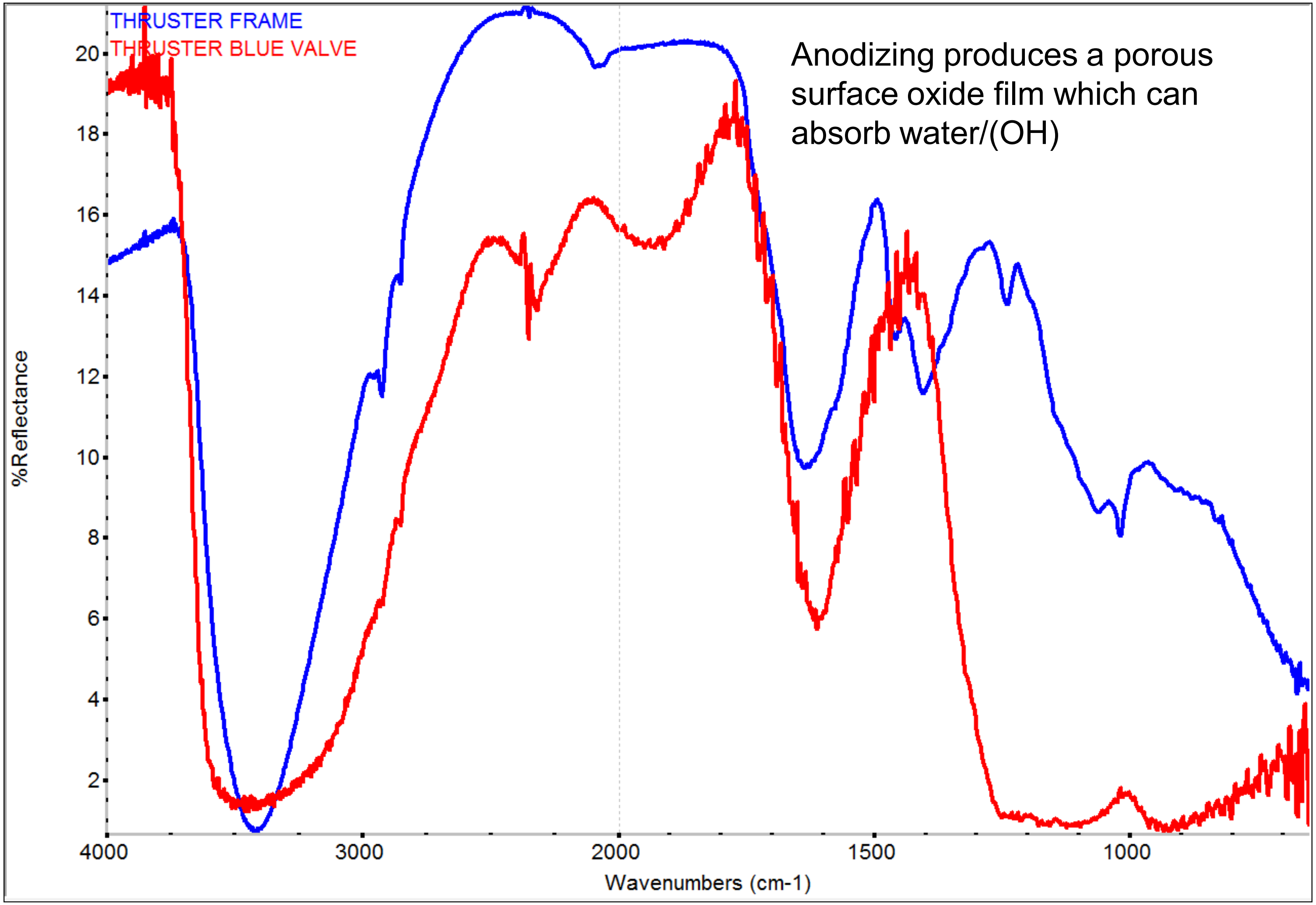
Pre Test (Exoscan): Untreated metal surfaces

Qualitative Biconical Reflectance



Metals do not produce spectral features.
Reflectance is dependent of surface roughness

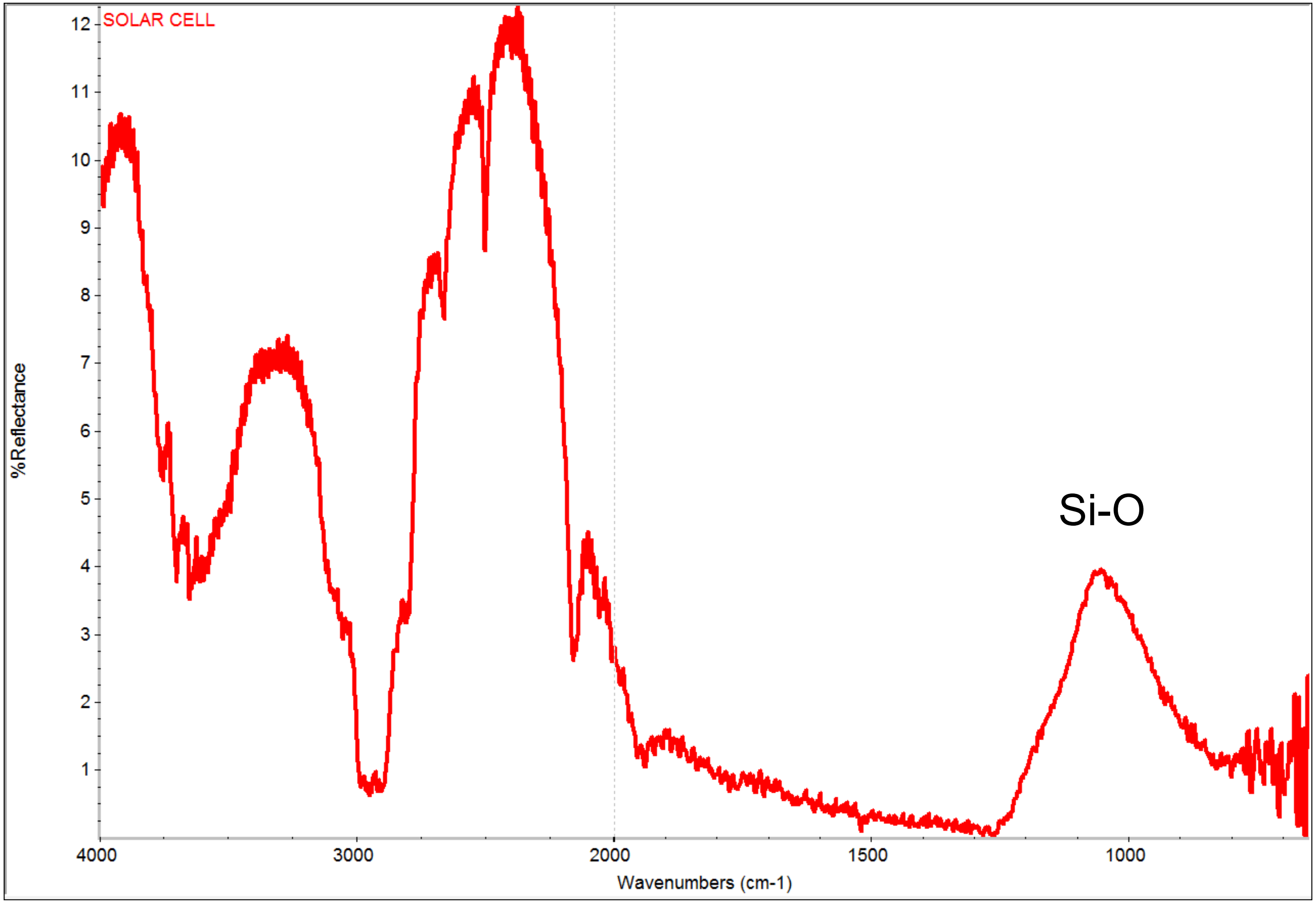
Pre test (Exoscan): Treated metal surfaces



Anodizing produces a porous surface oxide film which can absorb water/(OH)

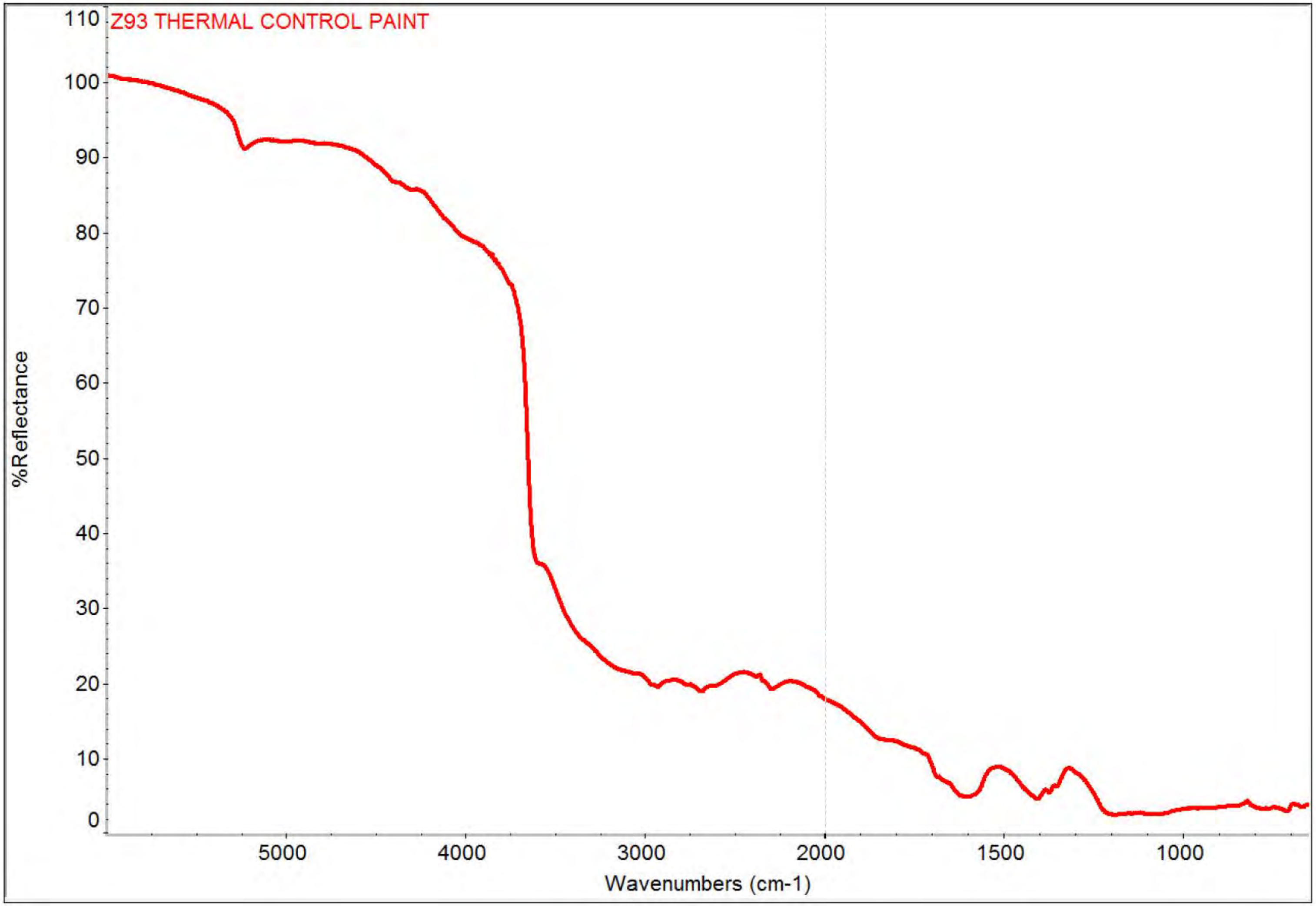
Note strong (OH)/H_2O bands at 3700-3000 cm^{-1} and 1700-1600 cm^{-1}; oxide bands at 1300-800 cm^{-1}.

Pre Test (Exoscan): Solar Cell from Witness Plate Assembly



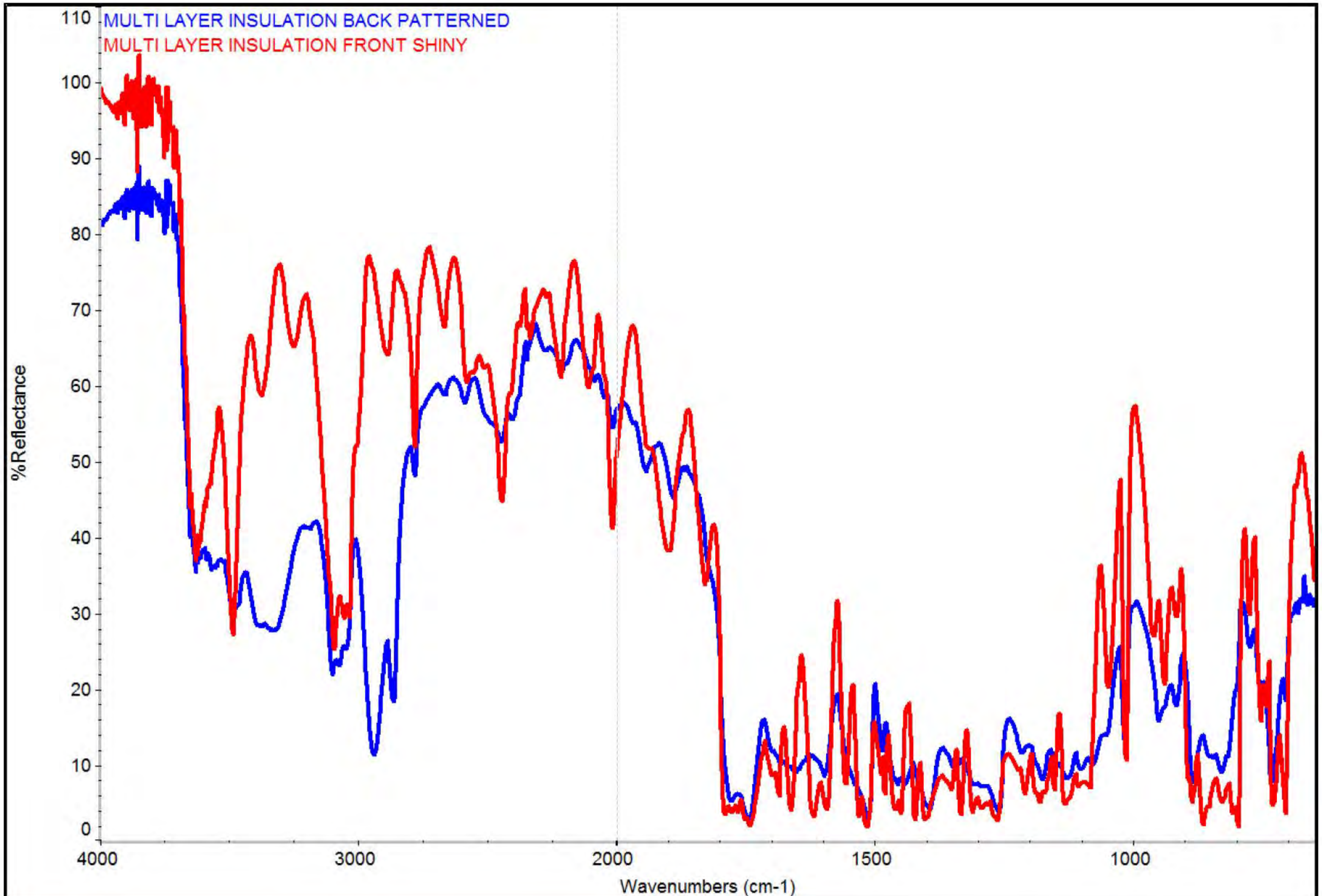
Reflectance maximum from silicate feature at 1050 cm^{-1}

Pre Test: Z-93 Thermal Control Paint from Witness Plate Assembly



Z-93 consists of ZnO particles in a K-silicate binder

Pre Test (Exoscan): Multi Layer Insulation from Witness Plate Assembly



Complex spectrum with many distinctive features

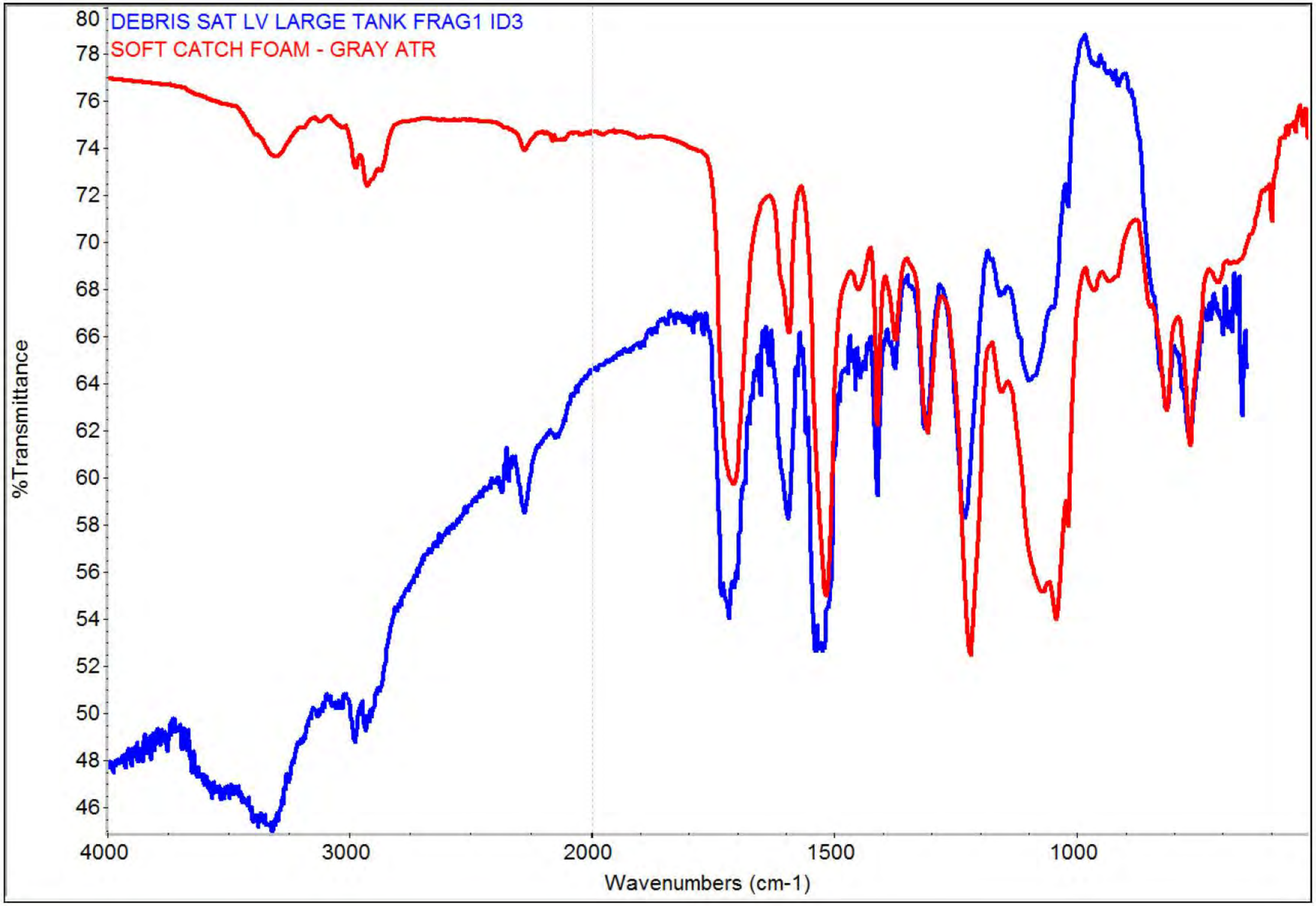
Main aluminum tank

Before After impact

Main aluminum tank: Post test

Outer and inner surfaces covered with a dark coating

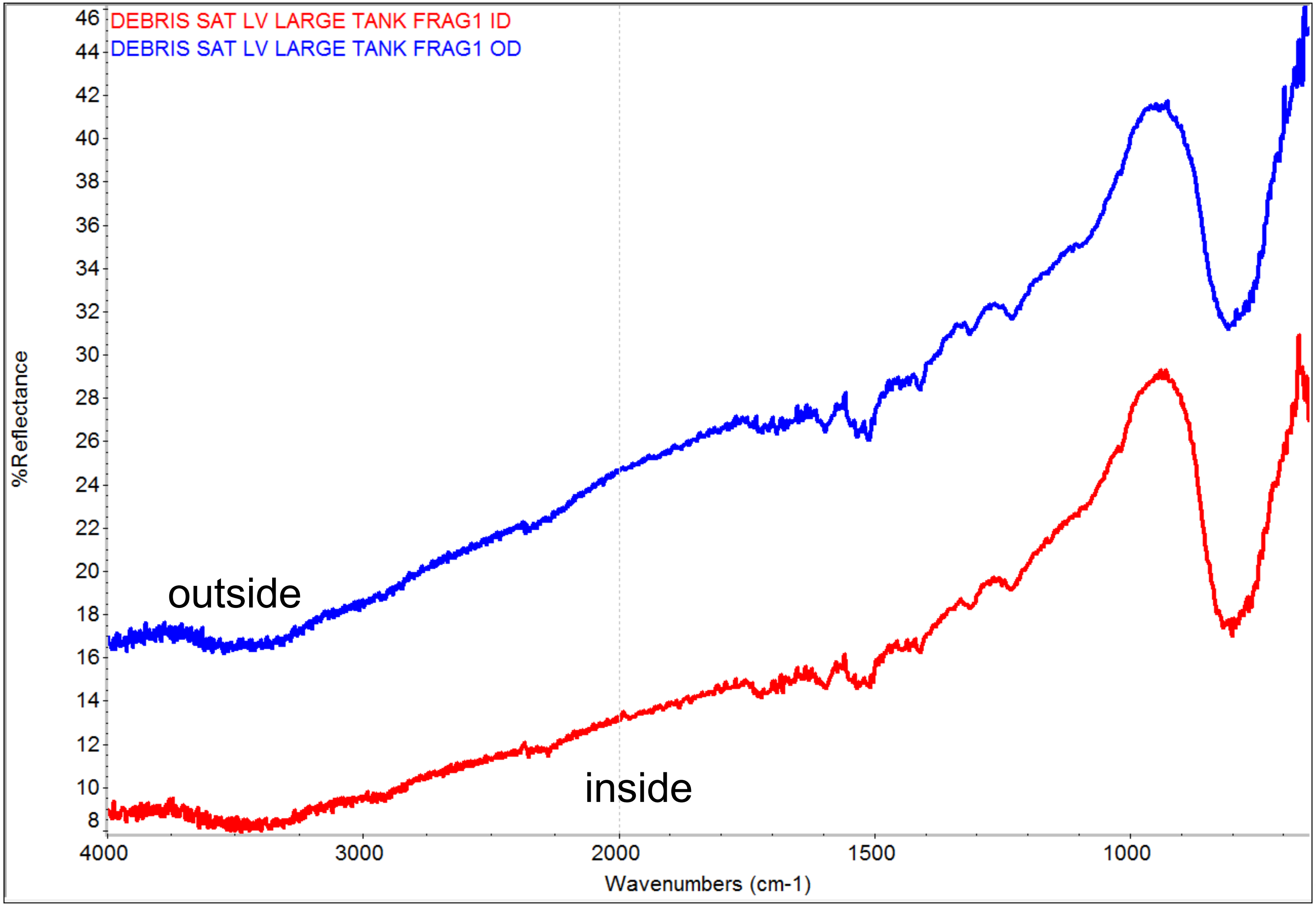
Post Test: Large Tank Fragment



Soft catch “dust” is present on many fragment surfaces

Post Test: Large Tank Fragment :

Collected day after test at AEDC with Exoscan



Many other areas have minimal soft catch contamination.
Note reflectance minimum "oxide" band at 800 cm^{-1}.

Witness Plate Assembly: Pre Test

Witness Plate Samples:

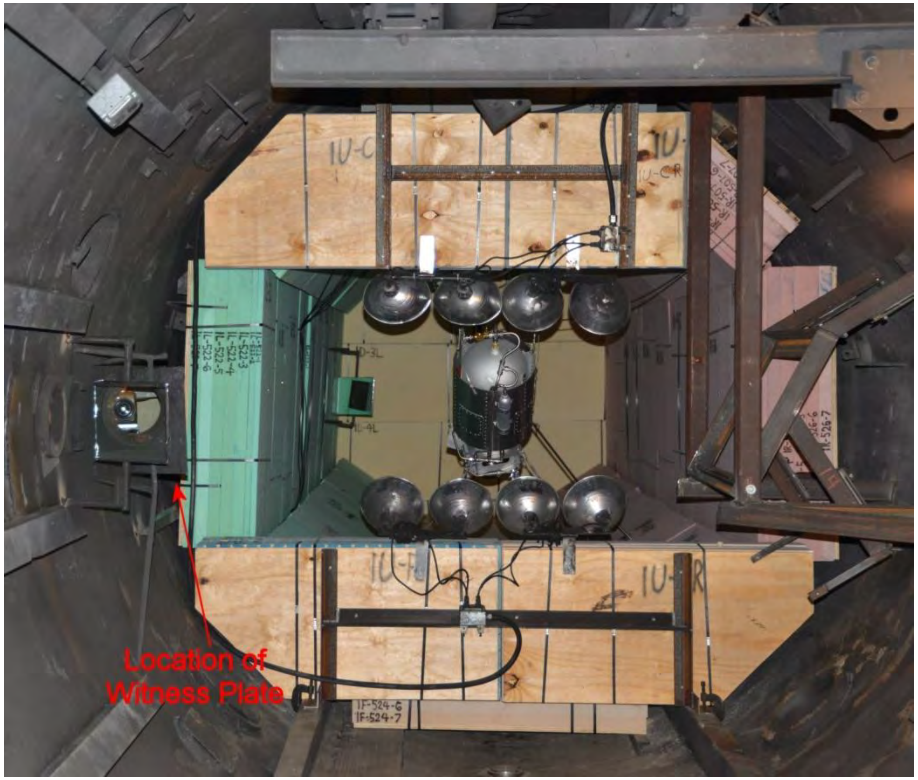
Direct Exposure

(4) 1” fused silica
(1) 1” Z-93 painted Al
(1) 1” Aluminum
Multi layer insulation (not shown)

Protected Under Whipple Plates

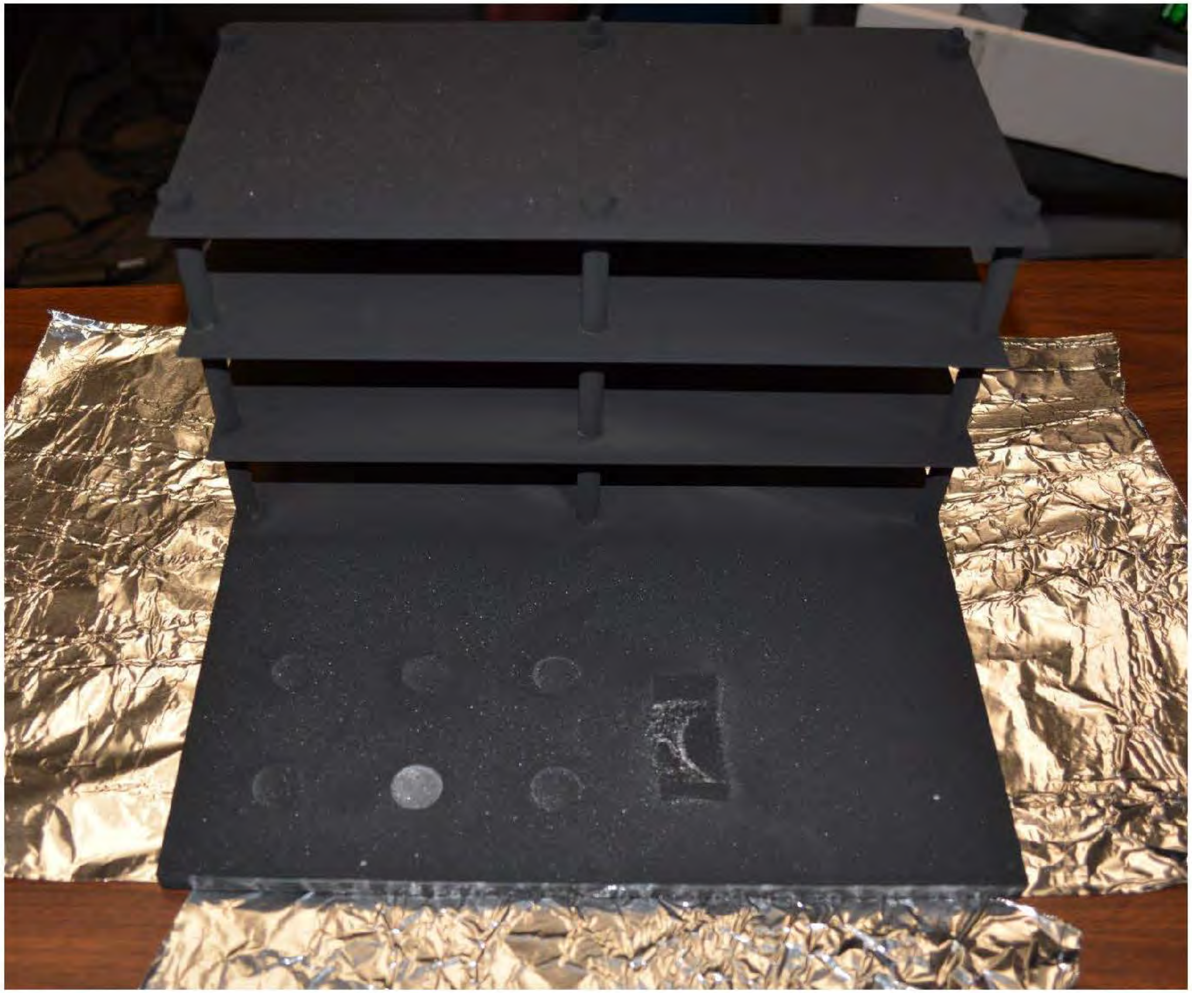
(2) 1” fused silica
(1) 1” Z-93 painted Al
(1) 1” Aluminum
(1) 1” NaCl
(1) Cu sheet
Ge ATR crystal
Solar cell

Witness plates installed in chamber



Witness plate assembly installed about 2-3 meters up range of Debris-LV

Witness Plate Assembly: Post Test



Assembly is covered with a black sooty substance, even under the Whipple plates. There is significant darkening

Witness Plate Assembly : Post Test

Aluminum Disks (1" dia)

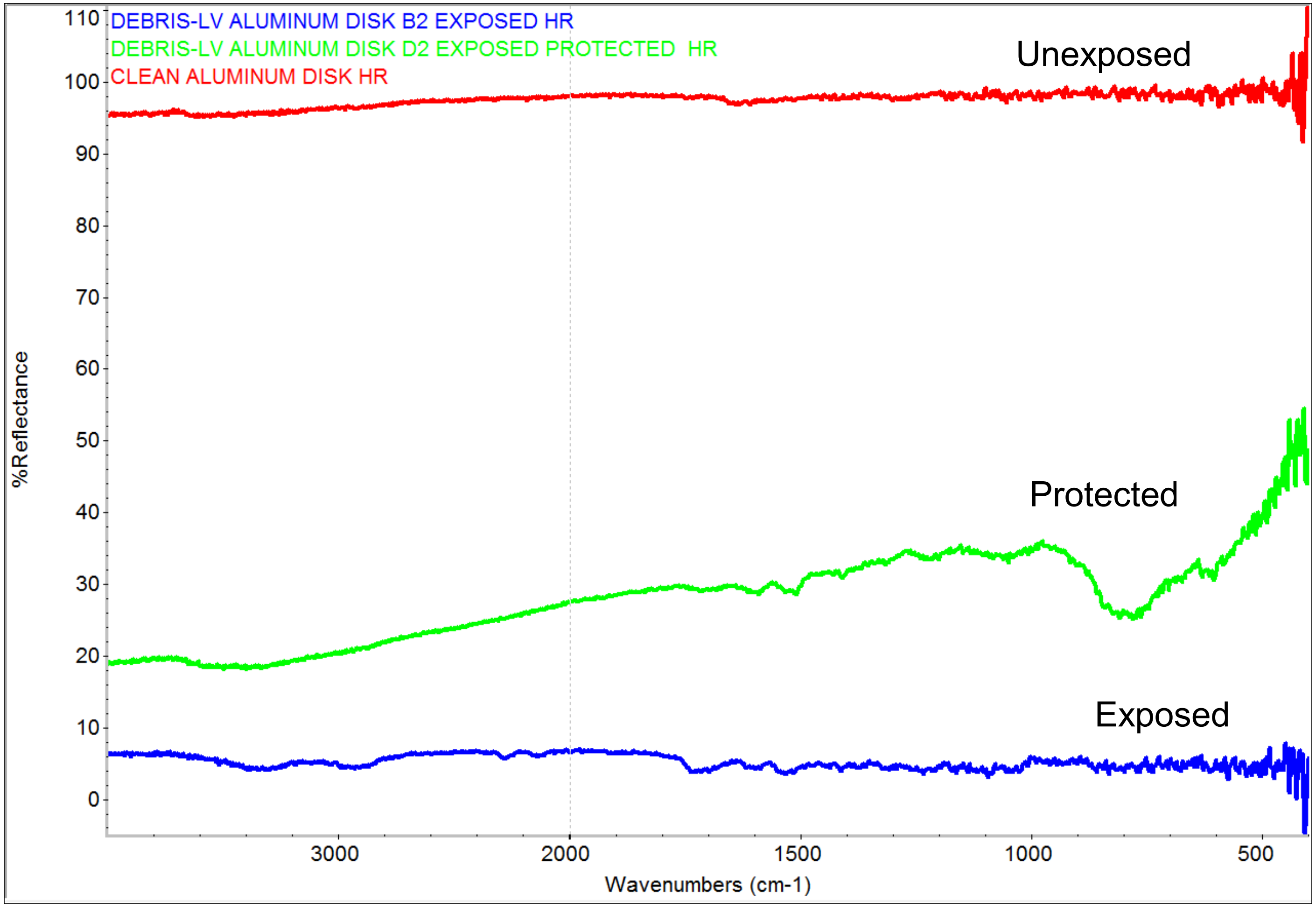
Directly exposed (B2)

Protected under Whipple plates (D2)

Directly exposed samples covered in coarse soft catch debris.
Less material under Whipple plates

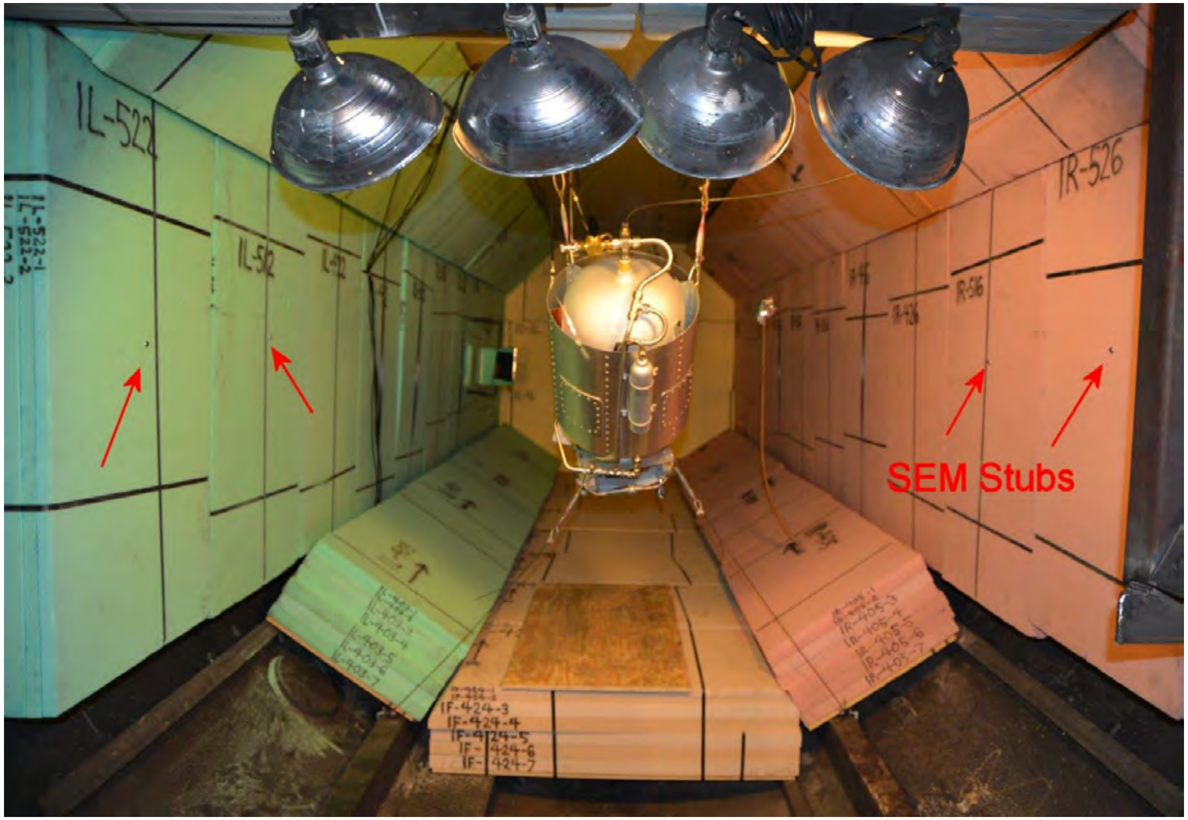
Post Test – Aluminum Disks

Quantitative Hemispherical Reflectance



Significant decrease in reflectance from 95% to 6% - "darkening".
Protected sample has reflectance minimum "oxide" band at 800 cm^{-1}.

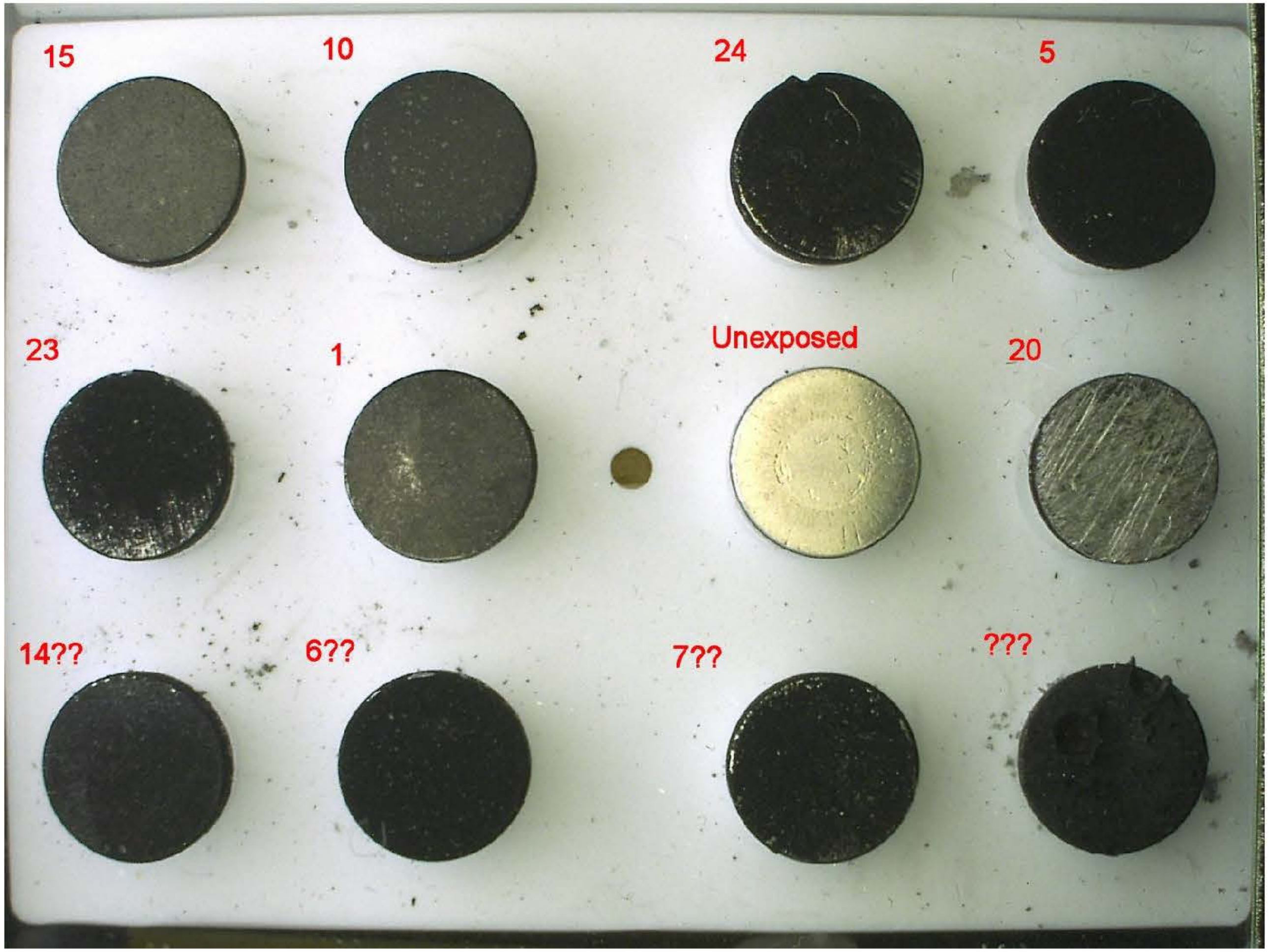
SEM Stubs Placed into Soft Catch Panels



SEM Stubs:
12.5 mm dia
aluminum

- 24 aluminum SEM stub witness plates (12.5 mm dia) placed in soft catch
- 19 stubs recovered; 16 identifiable, 3 recovered in place
- Most stubs covered in black “soot”

SEM Stubs: Pre and Post Test

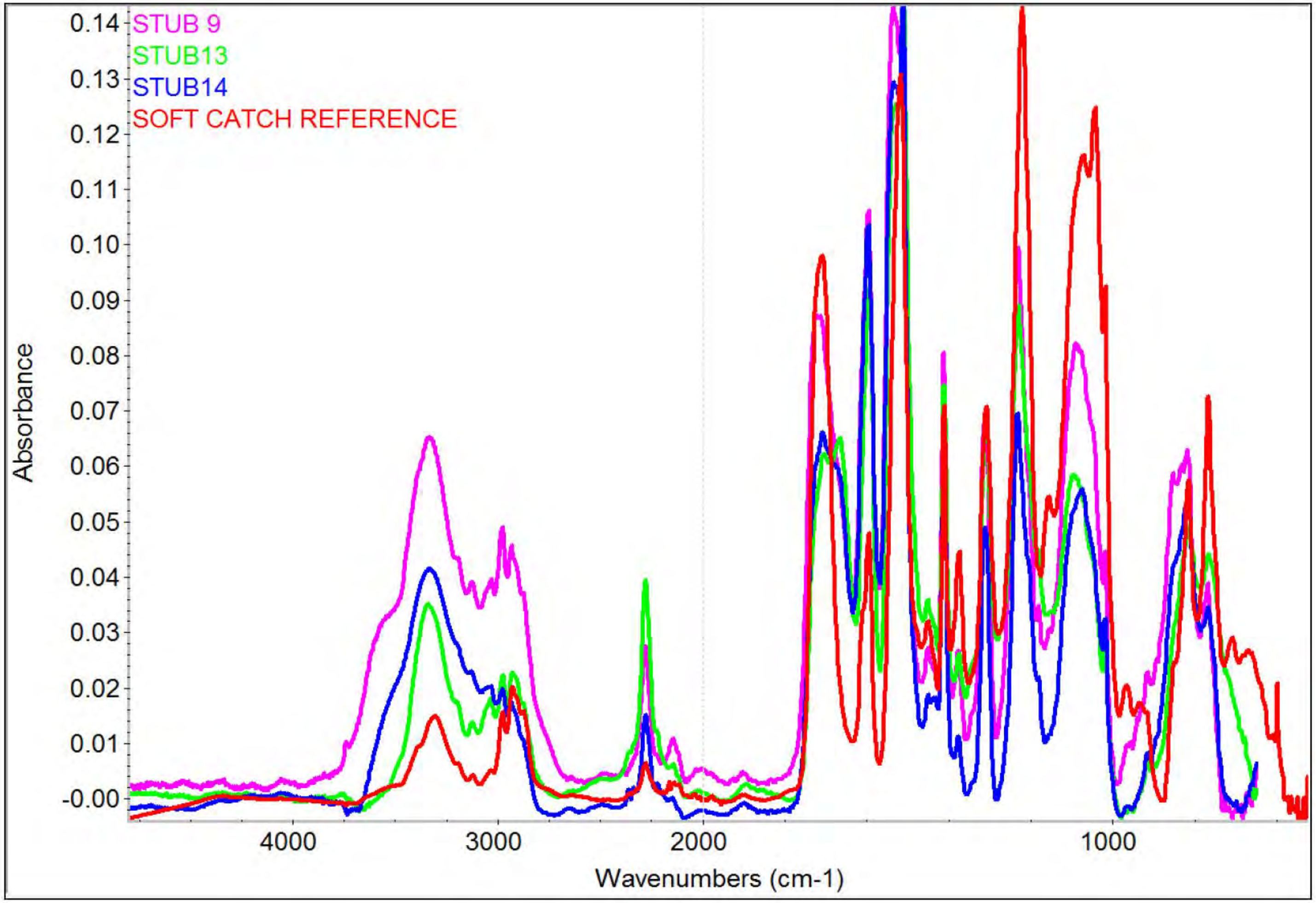


Exposed stubs show considerable darkening.

Light colored stubs 1, 10, 15 were recovered in place (up range) and show the least black “soot”.

SEM Stubs

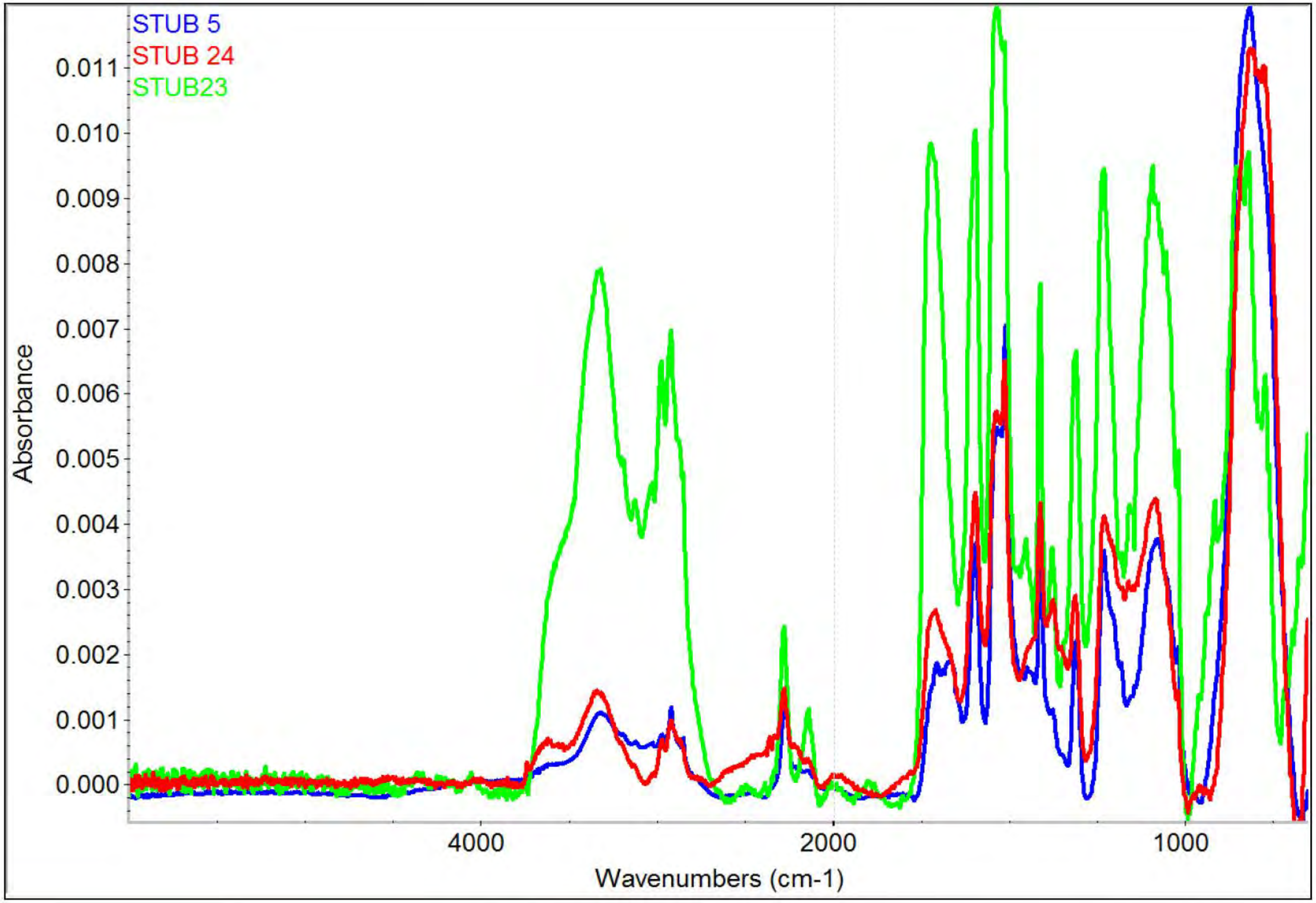
Qualitative Biconical Reflectance



Soft catch signature is common on SEM stubs

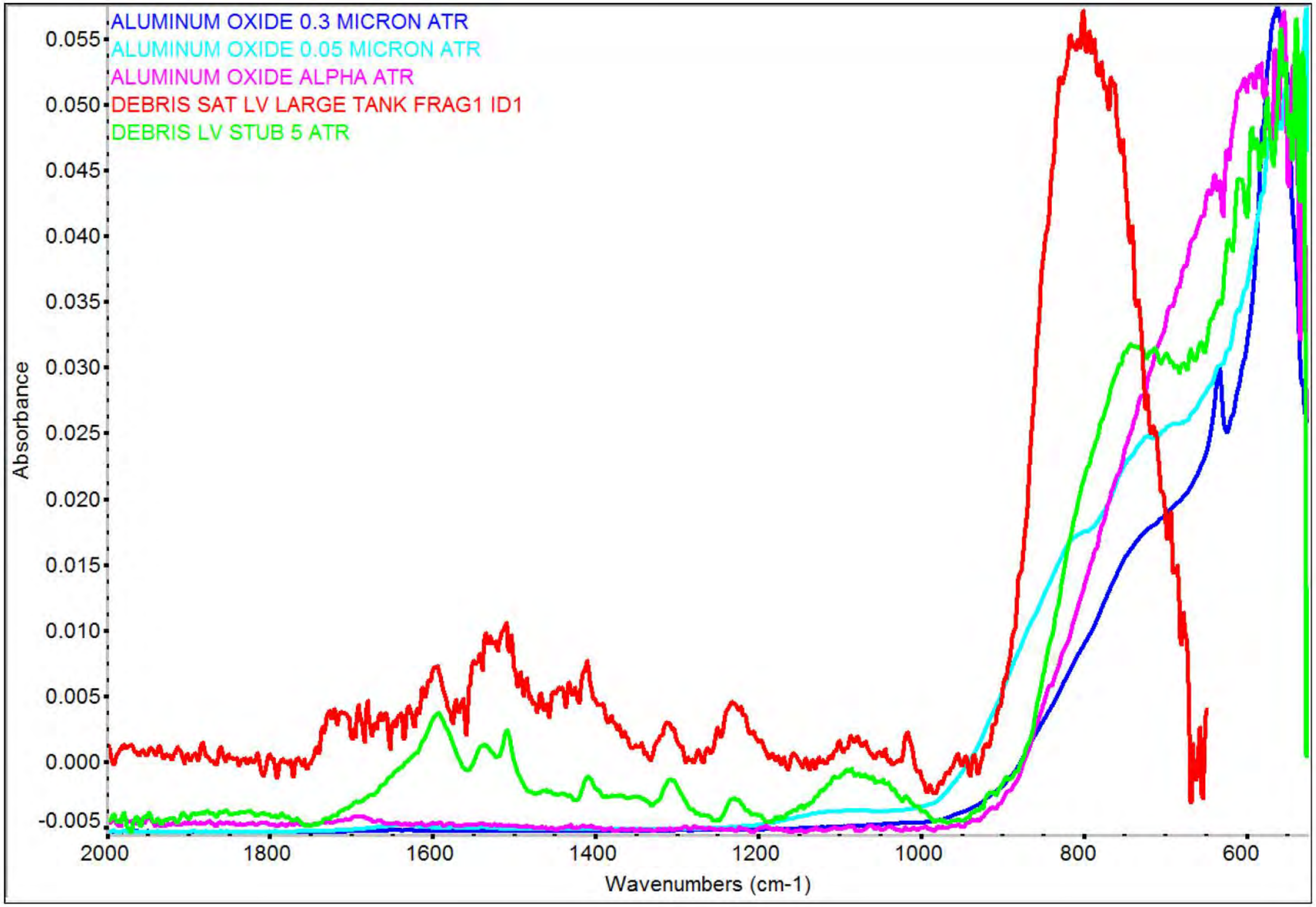
Dark Colored SEM Stubs

Biconical Reflectance



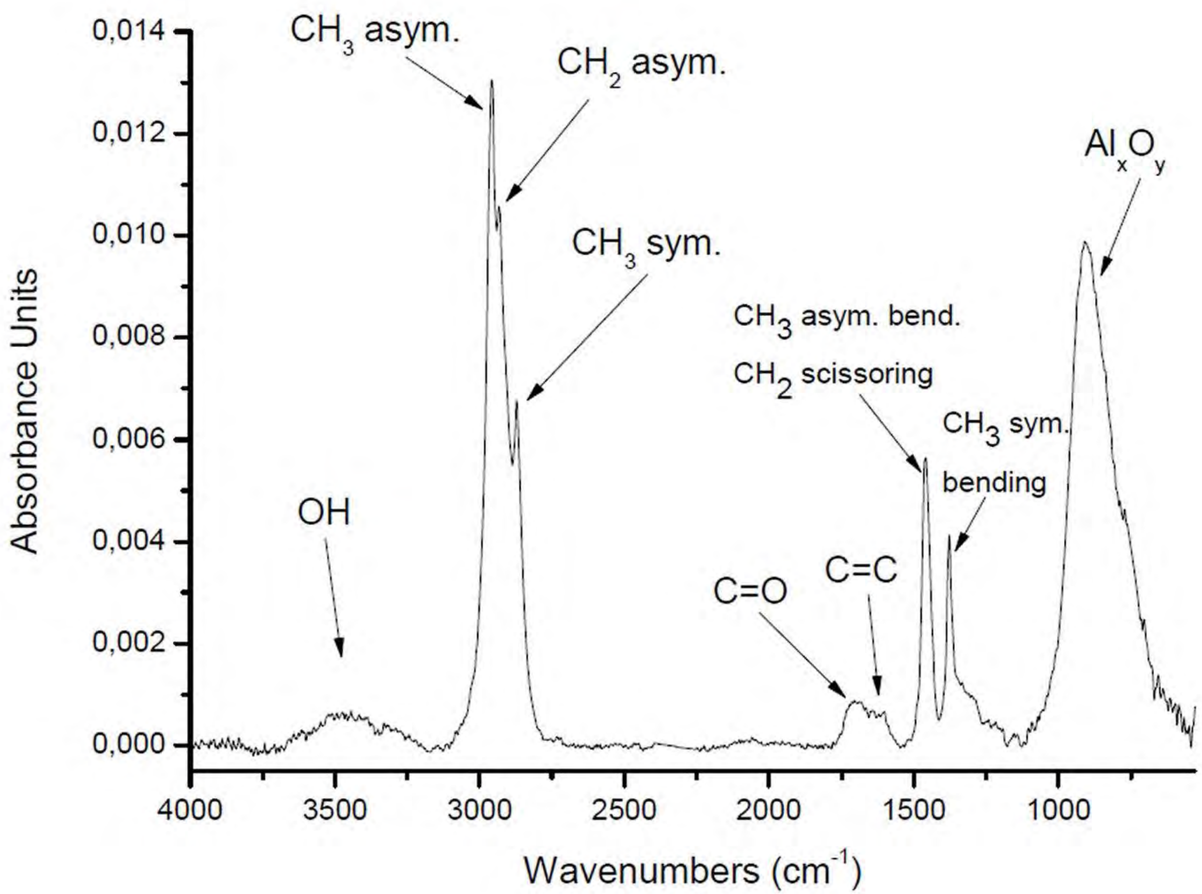
Soft catch foam debris common on witness plates.
Additional “oxide”(?) band at 800 cm^{-1} on dark sooty stubs.

Aluminum Oxide Spectra



EDS in the SEM and TEM indicate nano particles of aluminum and an aluminum oxide are present. The observed 800 cm^{-1} band is not a good match with common aluminum oxide reference materials.

Aluminum oxide nanoclusters have been reported in the literature



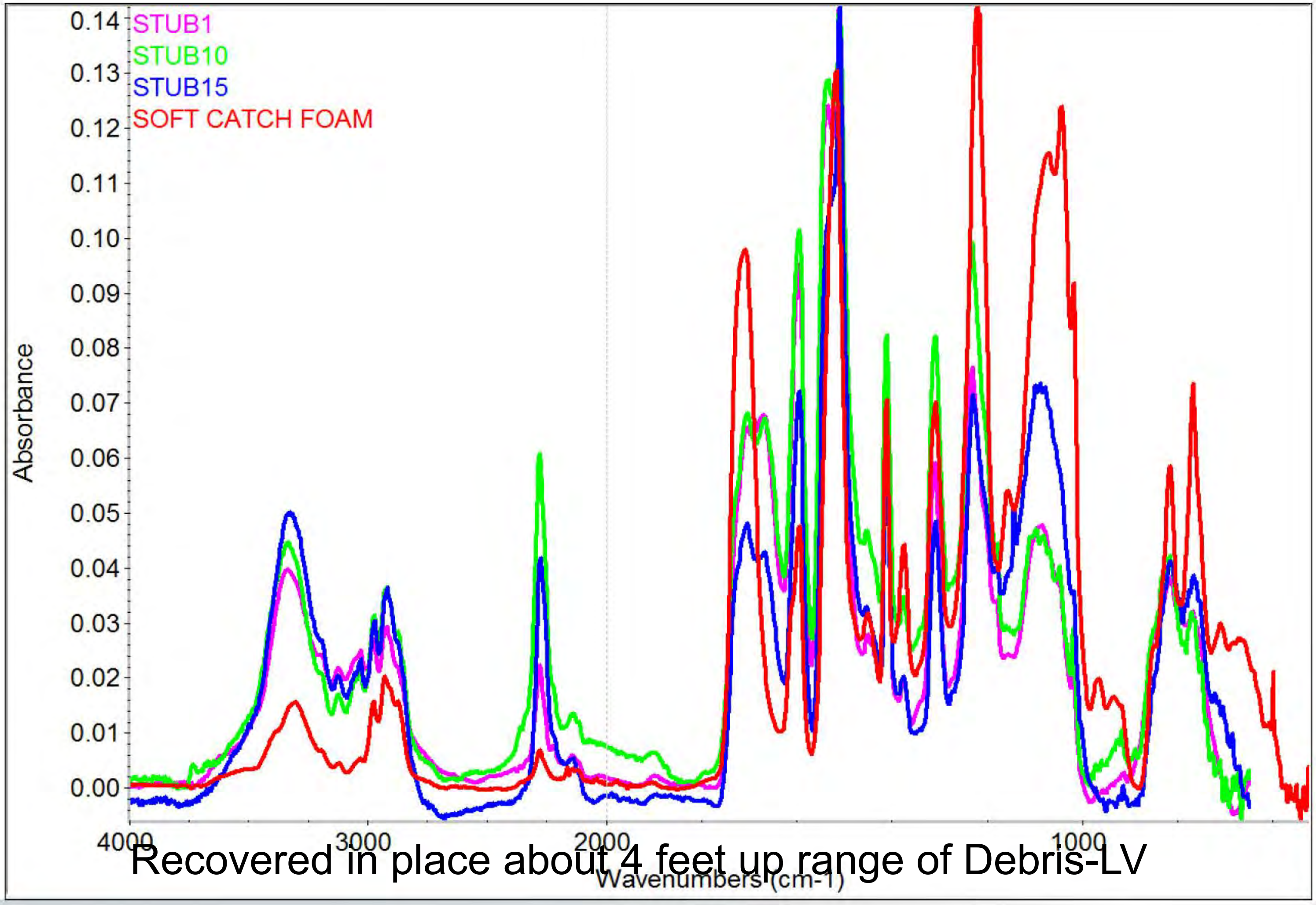
Similar “not fully recognized” feature near 850 cm^{-1} attributed to Al-O stretching vibrations in Al/Al_xO_y nano clusters (40-60 nm) produced by sputtering.

Organic (C-H) peaks are from polymer matrix

Aluminium oxide clusters and their nanocomposites with plasma polymers prepared by a gas aggregation cluster source and plasma polymerization.
O. Polonskyi, O.j Kylián, J. Kousal, P. Solař, A. Artemenko, A. Choukourov, D. Slavínská and H. Biederman, 19th International Symposium of Plasma Chemistry, Bochum, 2009.

Light Colored SEM Stubs

Qualitative Biconical Reflectance

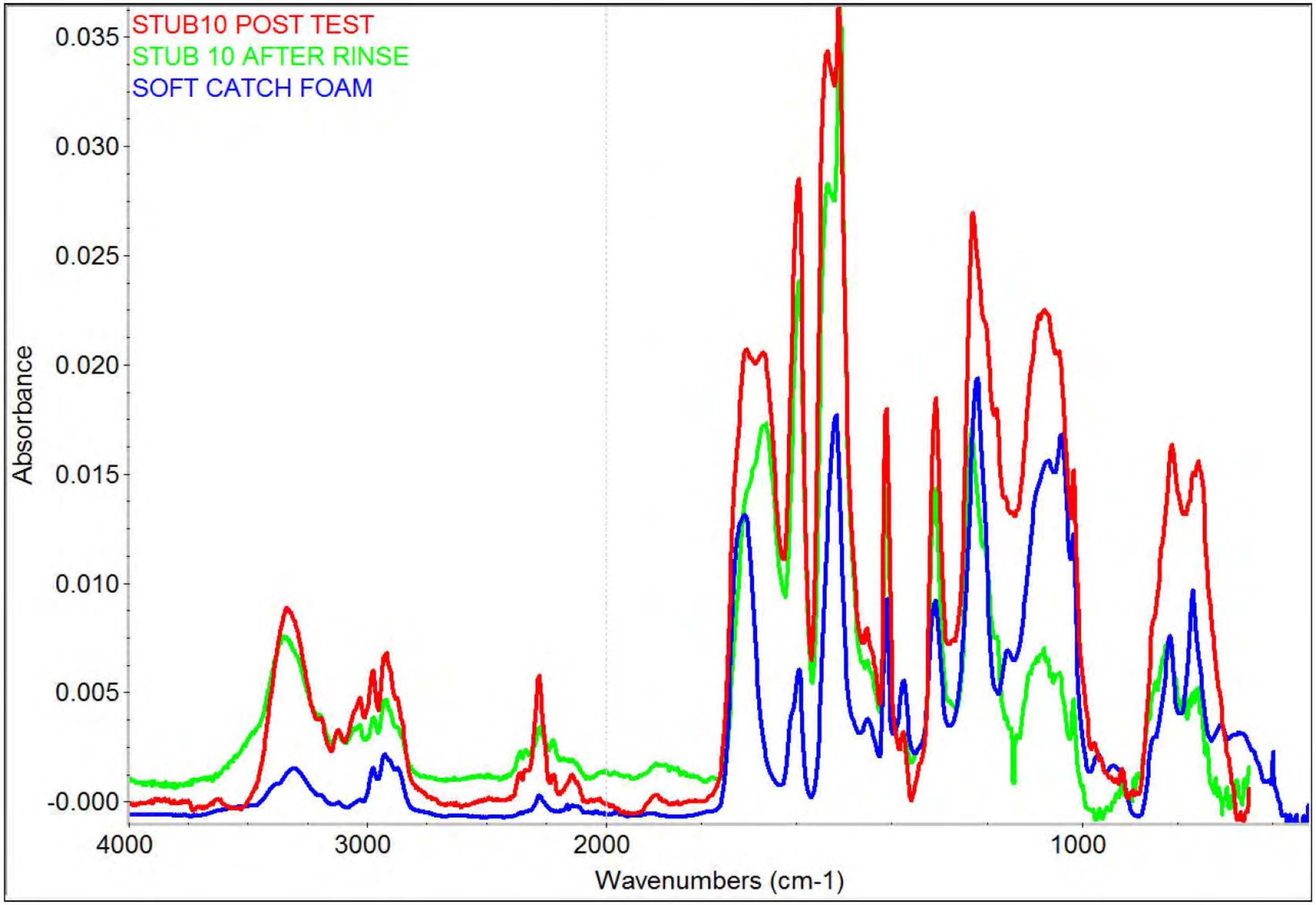


Recovered in place about 4 feet up range of Debris-LV

Light colored stubs have soft catch signature but little dust or soot on the surface. What causes the soft catch signature?

Stub 10 Post Test

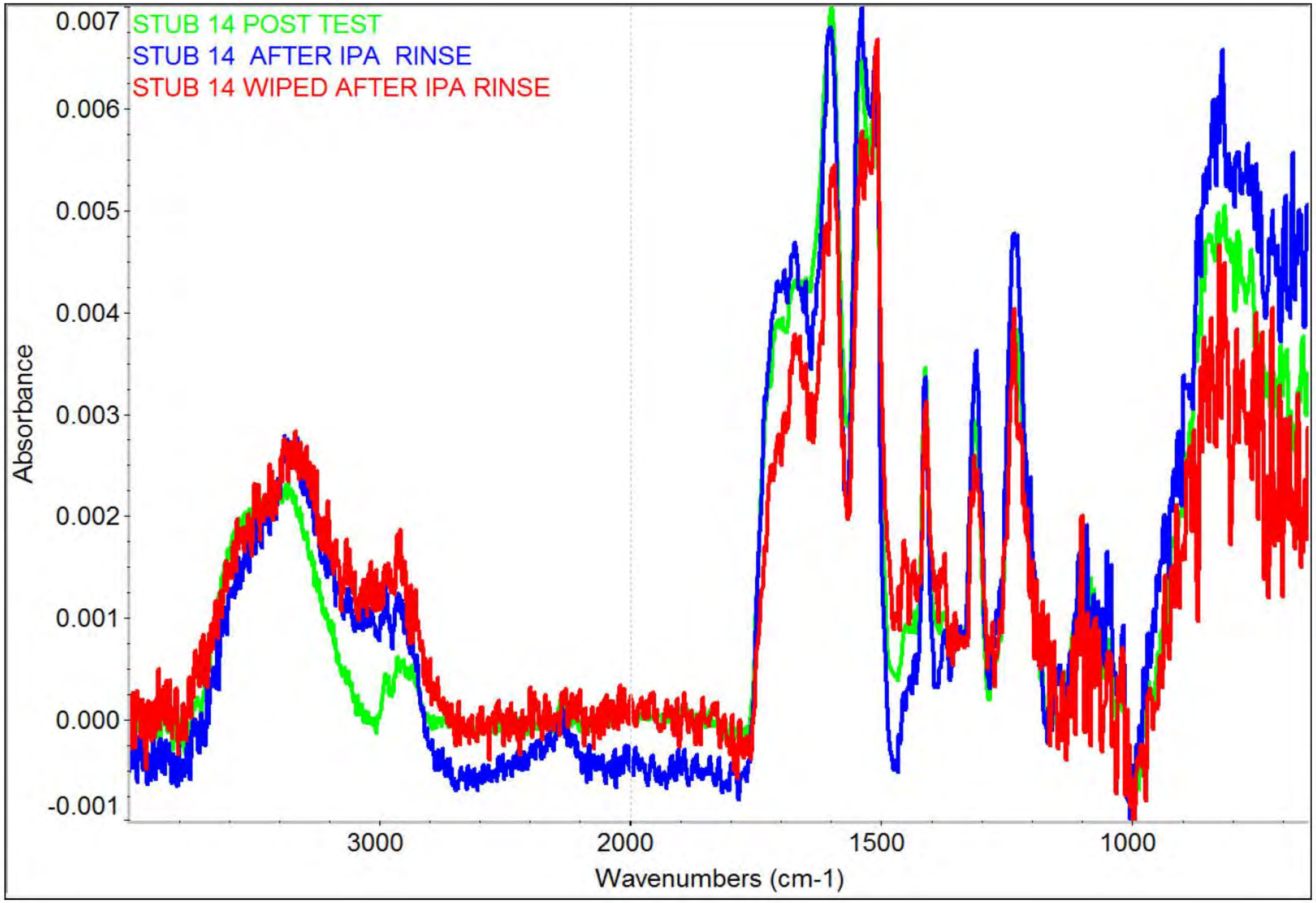
Qualitative Biconical Reflectance



Stub 10 was rinsed with isopropyl alcohol (IPA) and blown dry to remove loose soft catch fragments. Soft catch spectrum remained.

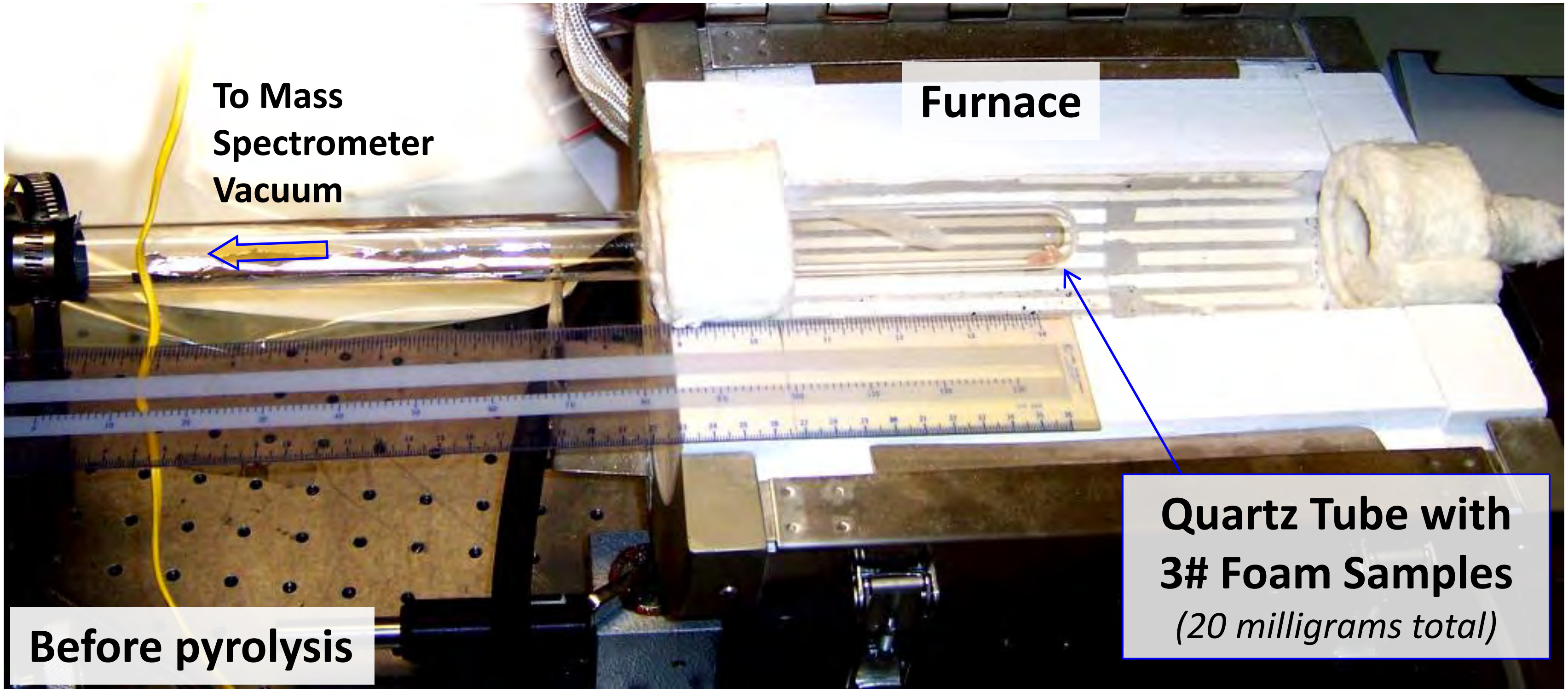
Stub 14 Post Test

Qualitative Biconical Reflectance



Stub 14 was located farther away (down range) from Debris-LV than Stub 10. Soft catch signature also remained after IPA rinse.

Laboratory Foam Pyrolysis Experiment



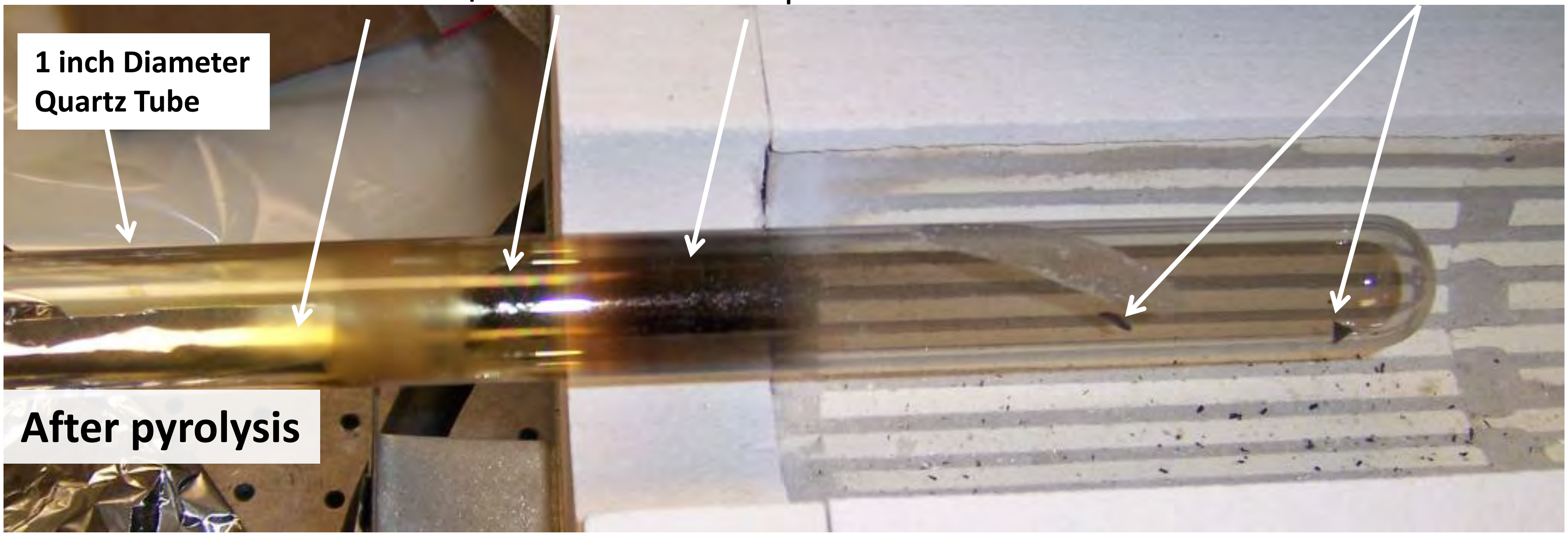
~ 0.001 Torr Throughout Pyrolysis => λ ~ 10 inches

30 milligram pieces of 3# foam pyrolyzed in a quartz tube under vacuum in order to simulate exposure to plasma from hypervelocity impact.

Condensate residues in cool portion of tube outside the furnace were analyzed by FTIR .

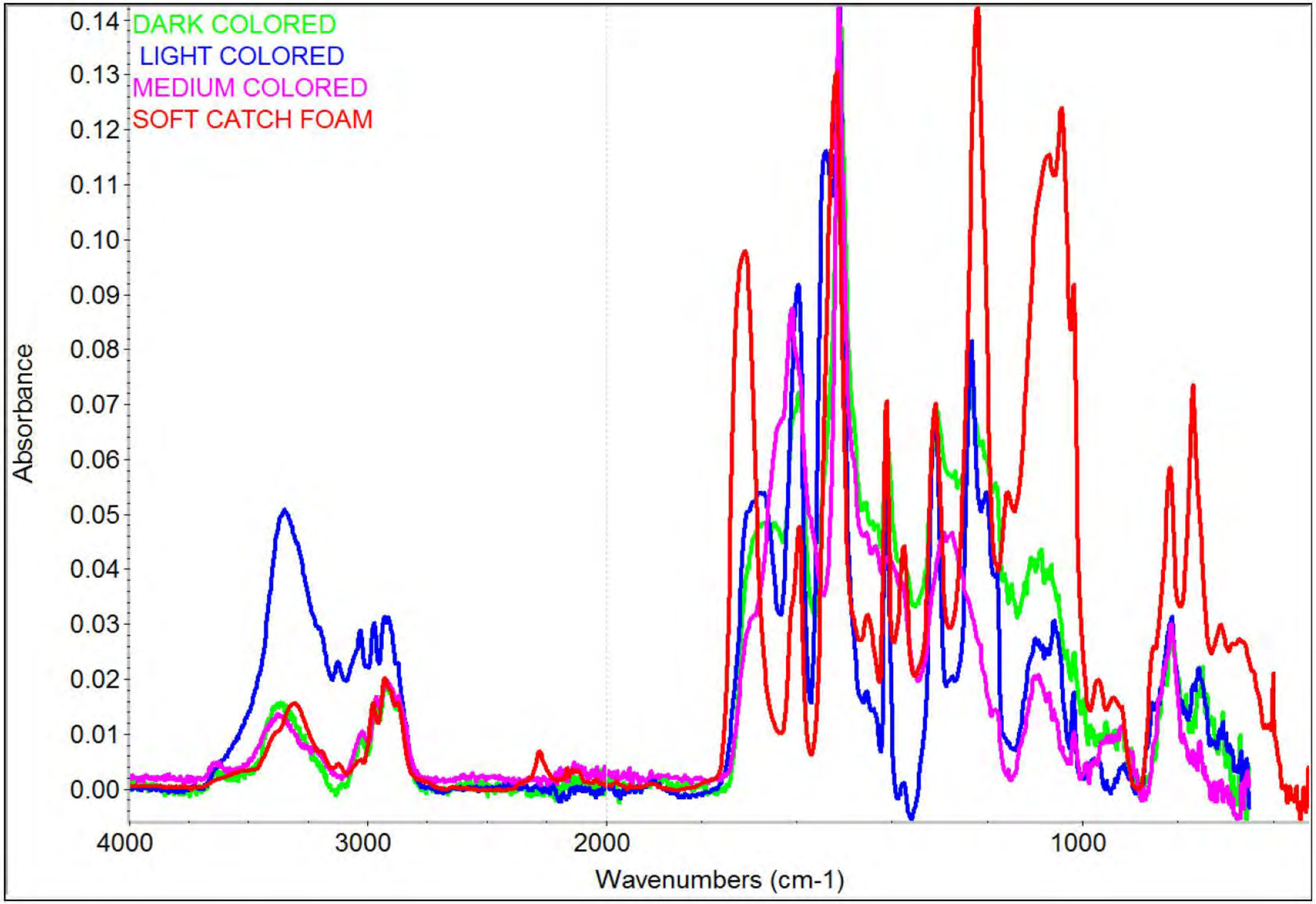
Laboratory Foam Pyrolysis Experiment

After Heating to 1000C



Condensate Removed from Tube

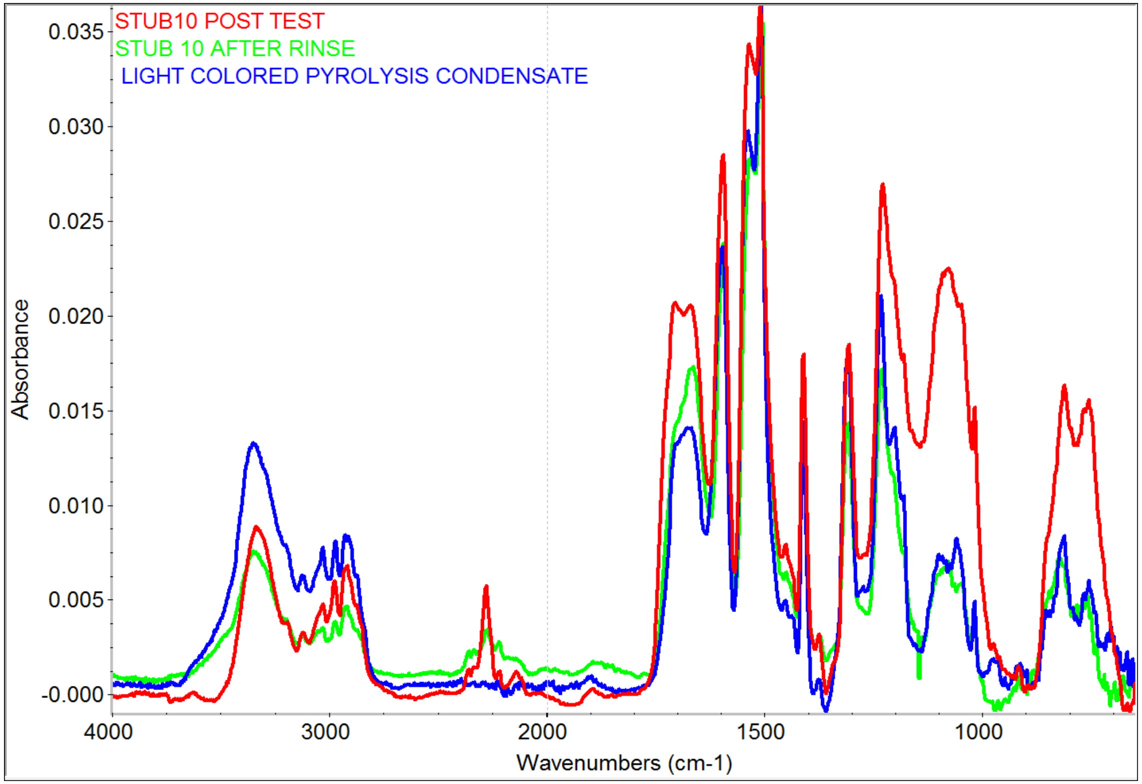
Qualitative Biconical Reflectance



Various colors of condensate have similar but slightly different spectra that resemble soft catch foam

Stub 10 vs. Pyrolysis Condensate

Qualitative Biconical Reflectance



- Spectrum of soft catch condensate similar to that on SEM stubs, before and after alcohol rinse. Alcohol rinse removed loose fragments.
- SEM stubs are covered with a thin layer of soft catch condensate in addition to fragments. Probably a result of close proximity to soft catch panels exposed to impact plasma.

Summary of Observations

- Significant darkening of witness plate occurred as a result of impact.
  - Drop from 90-95% to < 10% reflectance.
  - Greater than in pre preshot.
    - Deposited material is almost black while pre preshot was gray.
    - A result of soft catch debris?
    - Highly absorbing disordered graphitic carbon also detected by Raman and TEM.
- It was not possible to obtain a clean FTIR spectrum of the hypervelocity impact debris.
- In addition to soft catch fragments, SEM stubs are covered with a film condensed from vaporized soft catch foam.
  - SEM Stub #10 was rinsed with isopropyl alcohol (IPA) and blow dried to remove all loose soft catch debris. Soft catch spectrum remained.
  - Spectrum of condensed soft catch vapors is similar to material collected on SEM stub (before <u>and after IPA rinse</u>).
  - Stubs were placed on surface of soft catch and were in close proximity to any vaporized soft catch.

Summary of Observations (cont.)

- Post test tank fragments did not have soft catch condensed film but some loose soft catch debris.
- An aluminum oxide band at 800 cm^{-1} was observed on some areas of tank fragments and black sooty SEM stubs.
  - It appears to have been produced by the hypervelocity impact.
  - The source of the oxygen was probably the residual atmosphere (1-2 Torr) in the test chamber.
  - The formation of an oxide would not be expected on orbit.
  - Molten nano droplets of aluminum, iron and copper were identified by SEM-TEM-EDS
  - Aluminum oxide also detected by EDS.
- Witness plate assembly was heavily contaminated with soft catch debris/fragments.
- Additional laboratory analyses documented:
  - P.M. Adams, P. M. Sheaffer, Z. R. Lingley and G. Radhakrishnan, Debris-LV Laboratory Analyses, The Aerospace Corporation TOR-2015-00928.

DebriSat Test

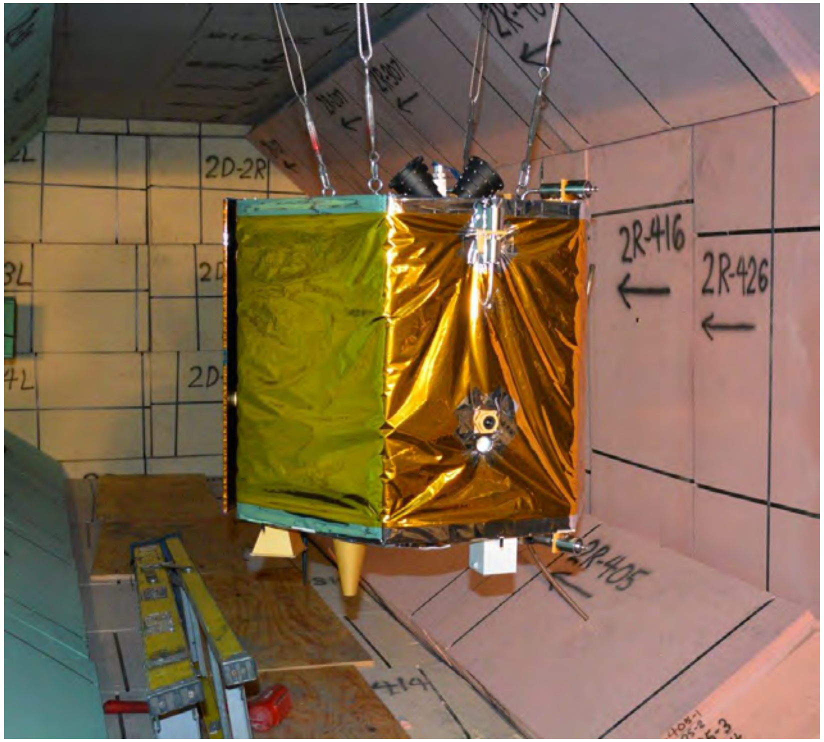
Introduction

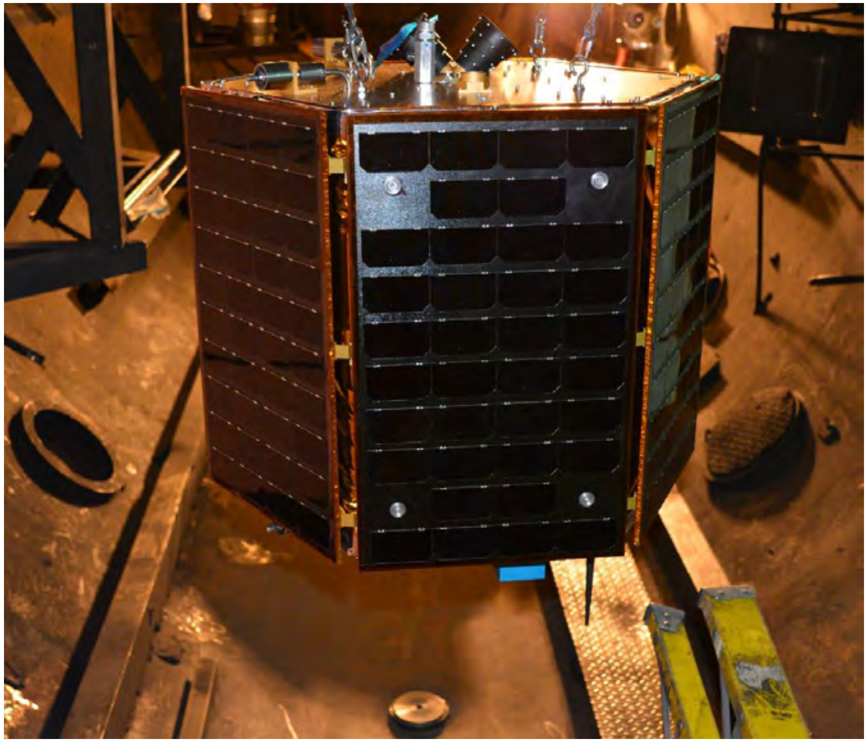
- Conducted 15 April 2014.
- The 56 kg target was constructed by the University of Florida from materials representative of a modern LEO satellite.
  - Aerospace Concept Design Center advised on selection of materials for various subsystems.
- Test chamber lined with “soft catch” foam panels to trap fragments for size distribution analysis.
- A witness plate assembly was constructed by Aerospace in order to catch and sample debris and returned to Aerospace after the test for analysis.
- Aerospace also placed SEM stub witness plates into soft catch for post test retrieval and analysis.
- Additional information in P.M. Adams, Z. R. Lingley, N. Presser and G. Radhakrishnan, DebriSat Laboratory Analyses, The Aerospace Corporation TOR-2015-00876.

Samples Analyzed

- Representative materials on exposed DebriSat surfaces.
  - With Exoscan portable FTIR: Pre test surfaces and post test fragments.
- Additional materials on witness plate assembly.
  - Multi layer insulation (MLI) , solar cell, Z-93 thermal control paint, aluminum.
  - Laboratory biconical and hemispherical reflectance: pre and post test.
- SEM stub witness plates placed on soft catch.
  - Biconical reflectance: Unexposed and exposed.

Installed in Chamber: Pre test





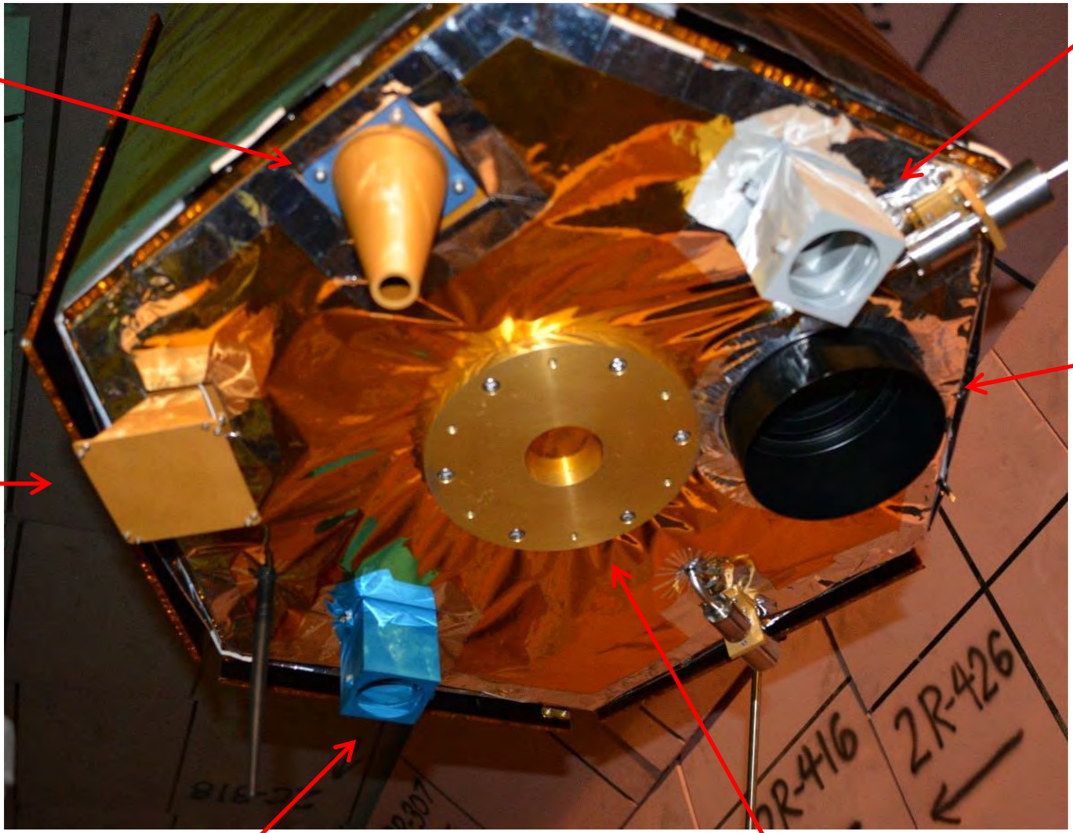
Looking down range.
Outer surface covered with multi layer insulation.

Looking up range.
Solar panels - undeployed

Nadir / Under Side

S-band
cone antenna

Spectrometer
Baffle (Bay 3)



Optical imager
sun shade

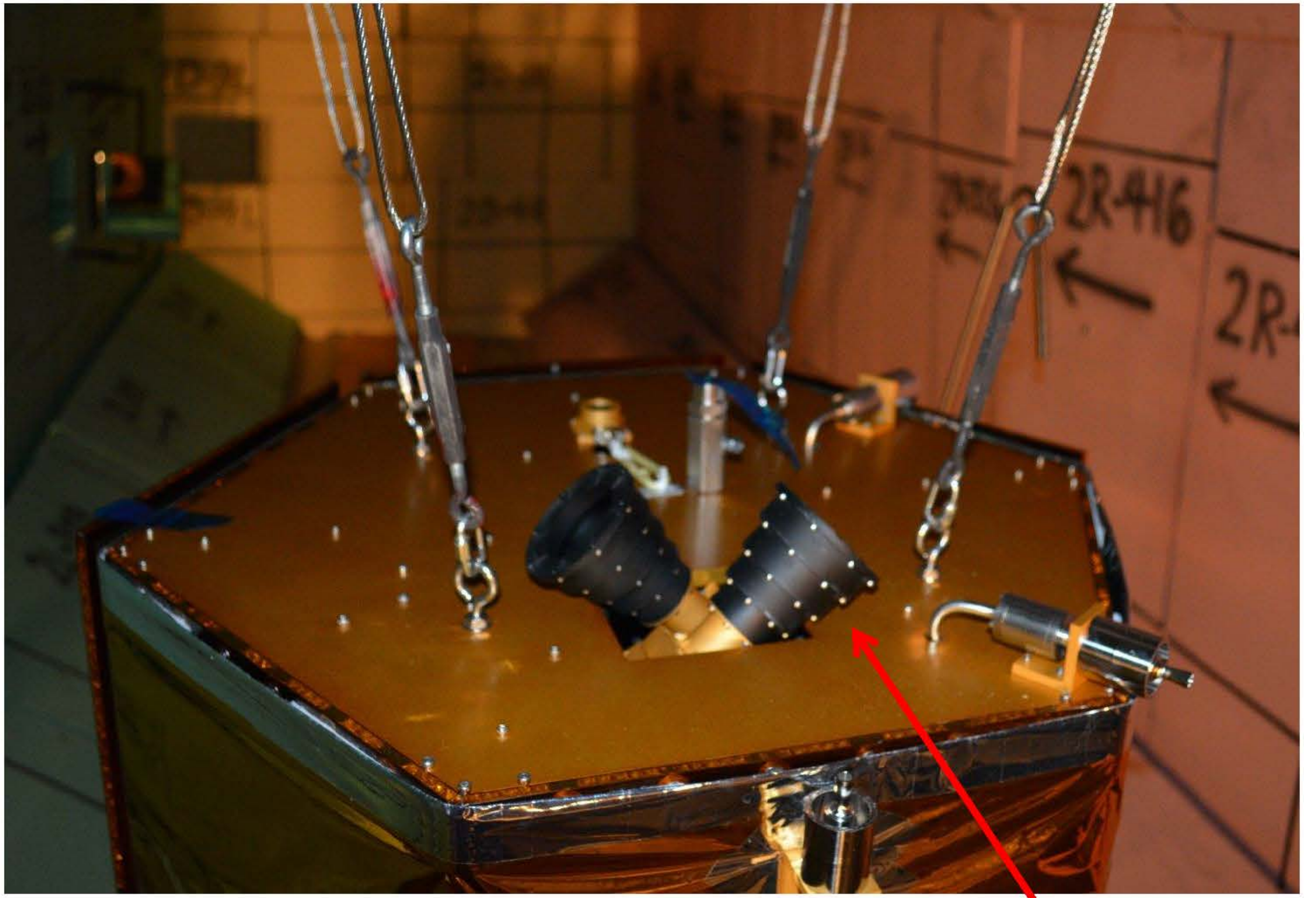
X-band
horn antenna

Spectrometer
Baffle (Bay 6)

Adapter plate

Most of the nadir components are made from anodized aluminum.

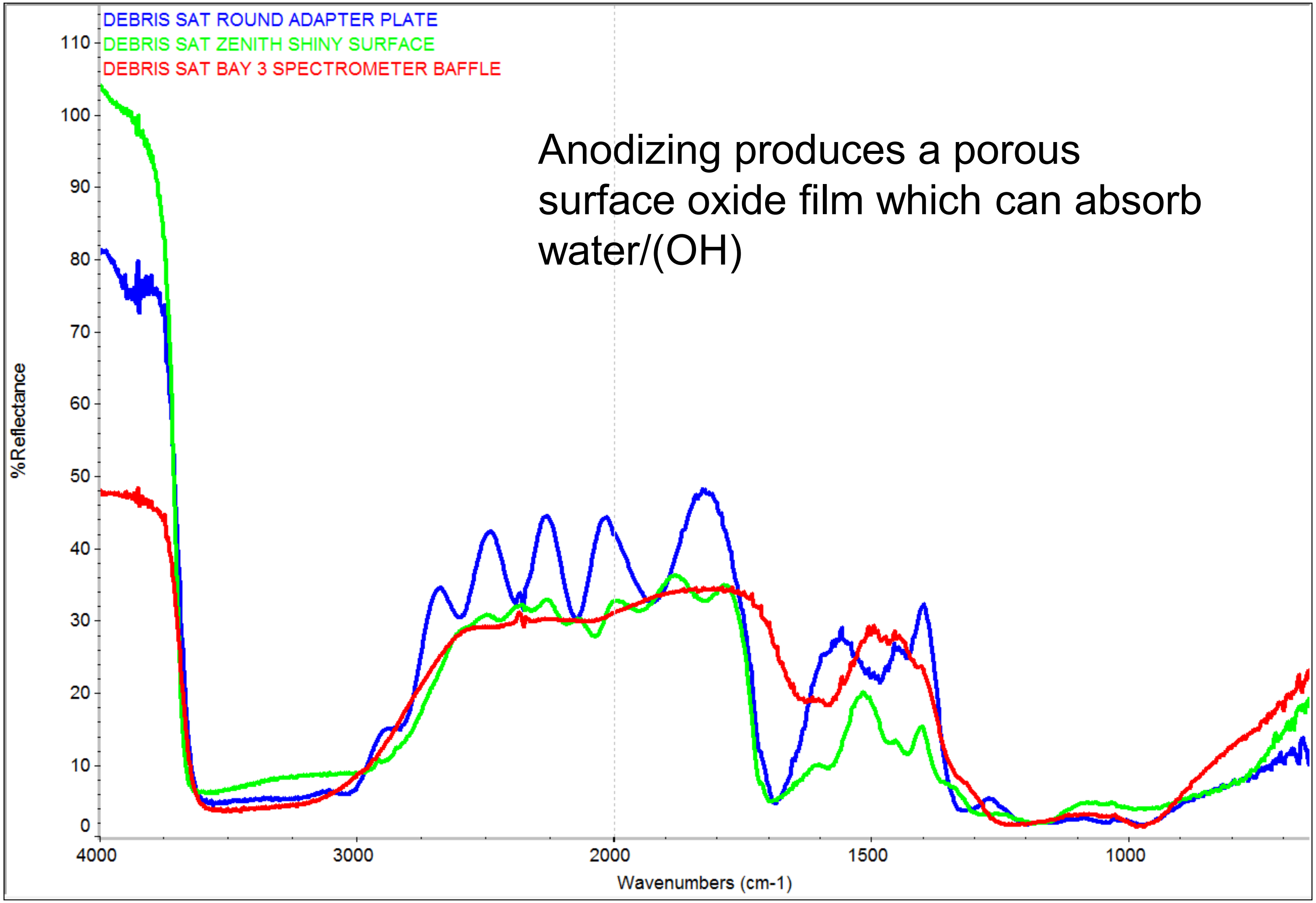
Zenith / Top Side



Star trackers

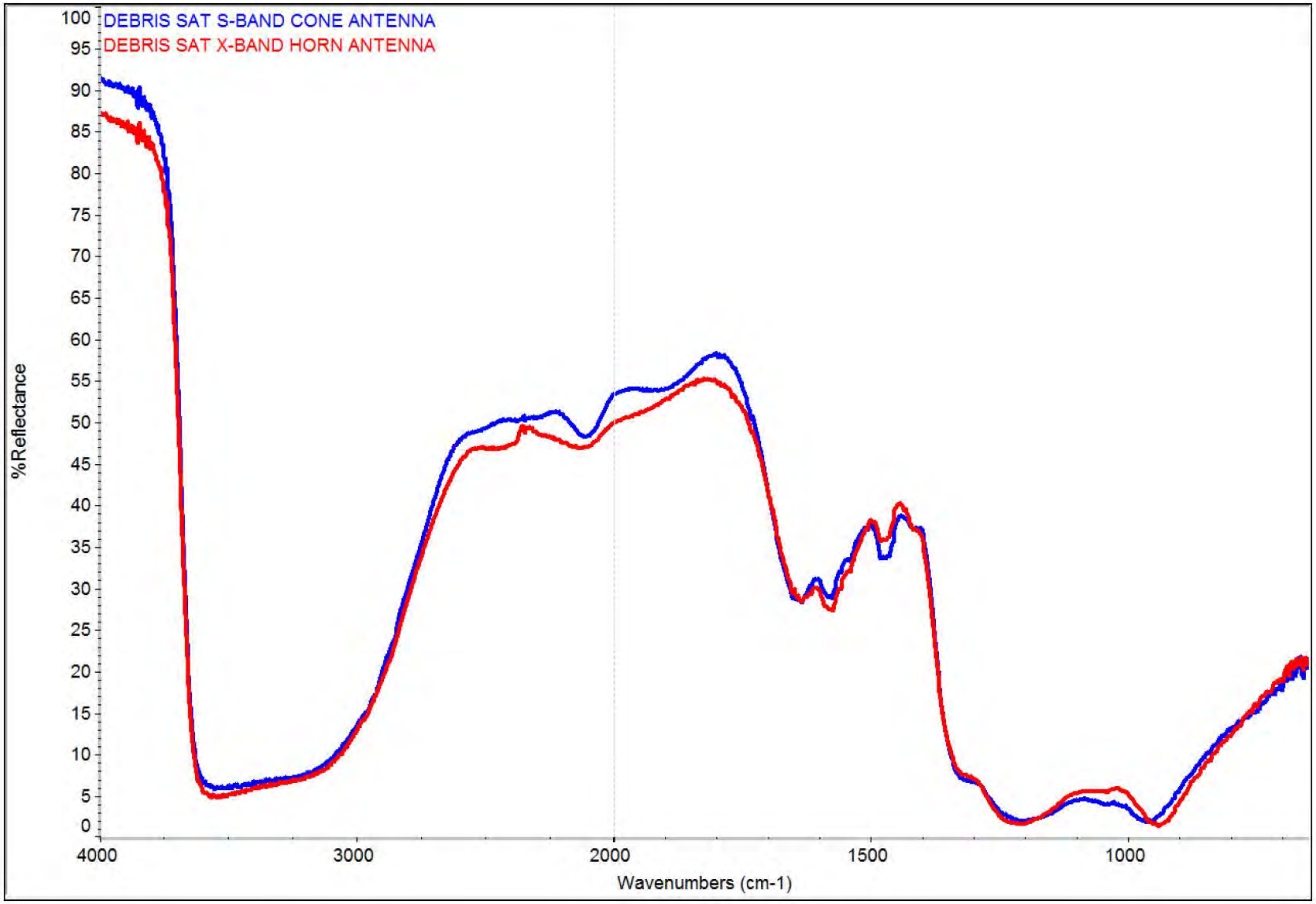
The zenith panel is made from anodized aluminum.

Pre Test Spectra: Anodized aluminum surfaces.



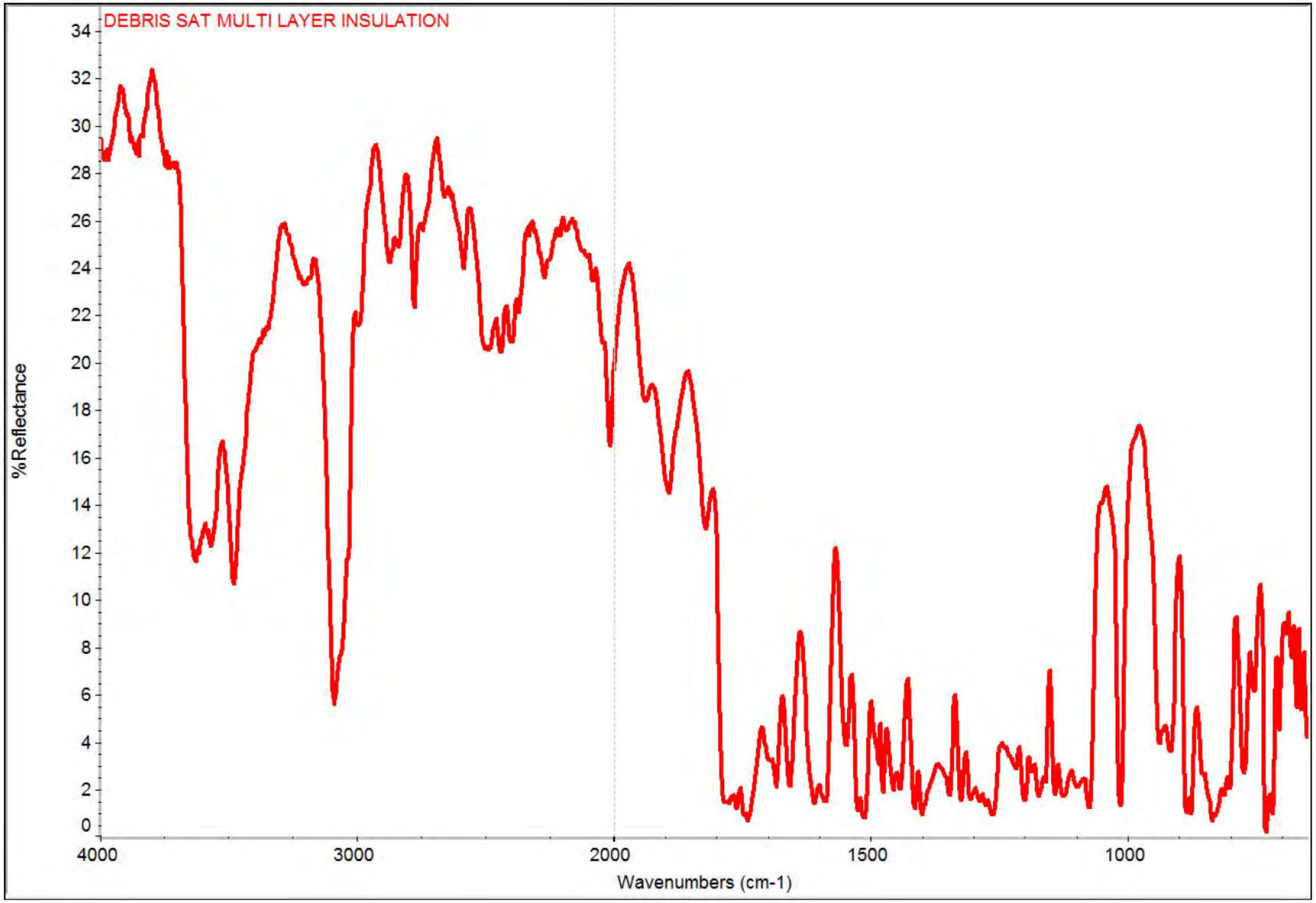
Note strong (OH)/H_2O bands at 3700-3000 cm^{-1} and 1700-1600 cm^{-1}; oxide bands at 1300-800 cm^{-1} and interference fringes (adapter plate).

Pre Test Spectra: Anodized aluminum surfaces.



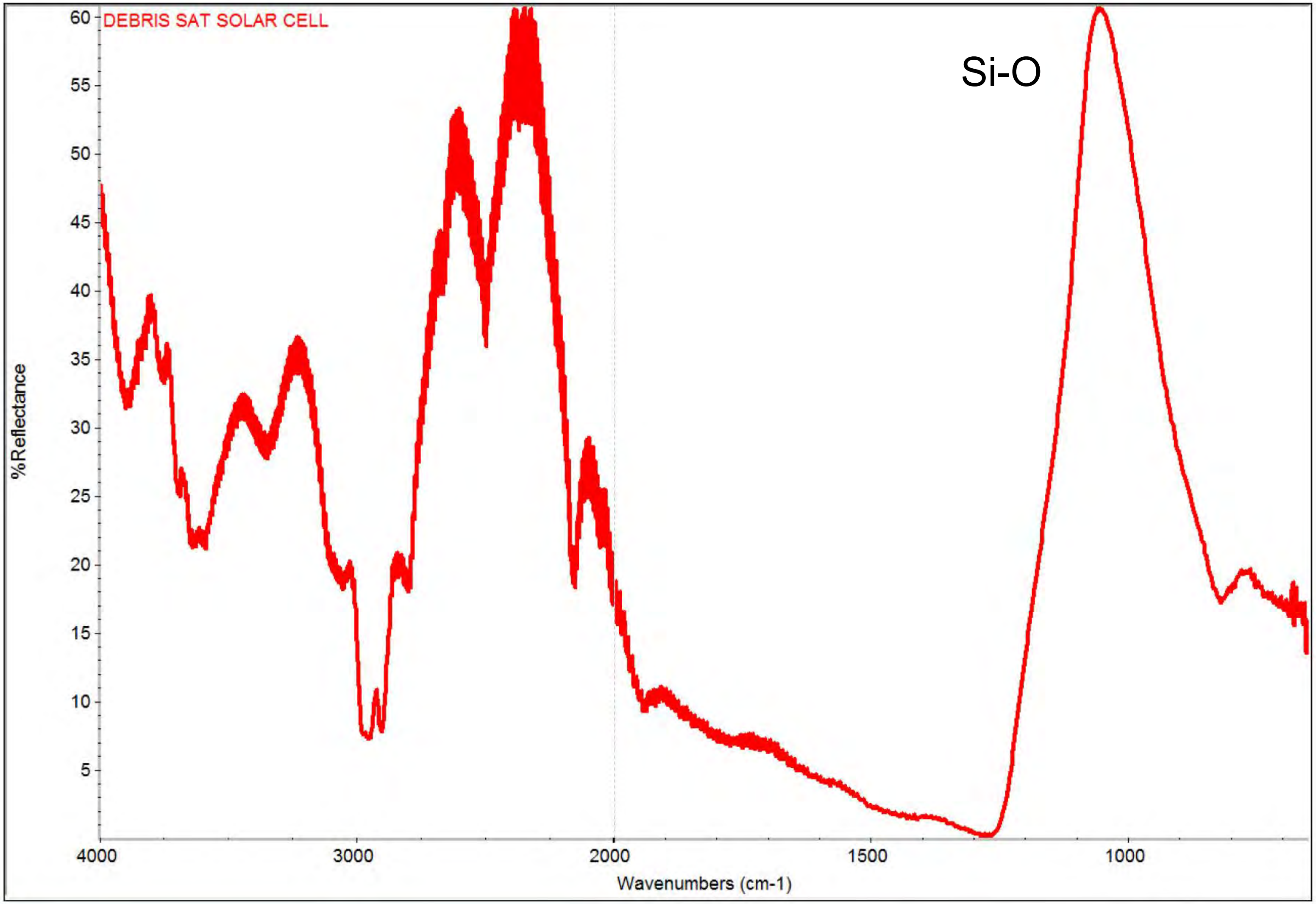
Note strong (OH)/H_2O bands at 3700-3000 cm^{-1} and 1700-1600 cm^{-1}; oxide bands at 1300-800 cm^{-1} and interference fringes.

Pre Test Spectra: Multi Layer Insulation



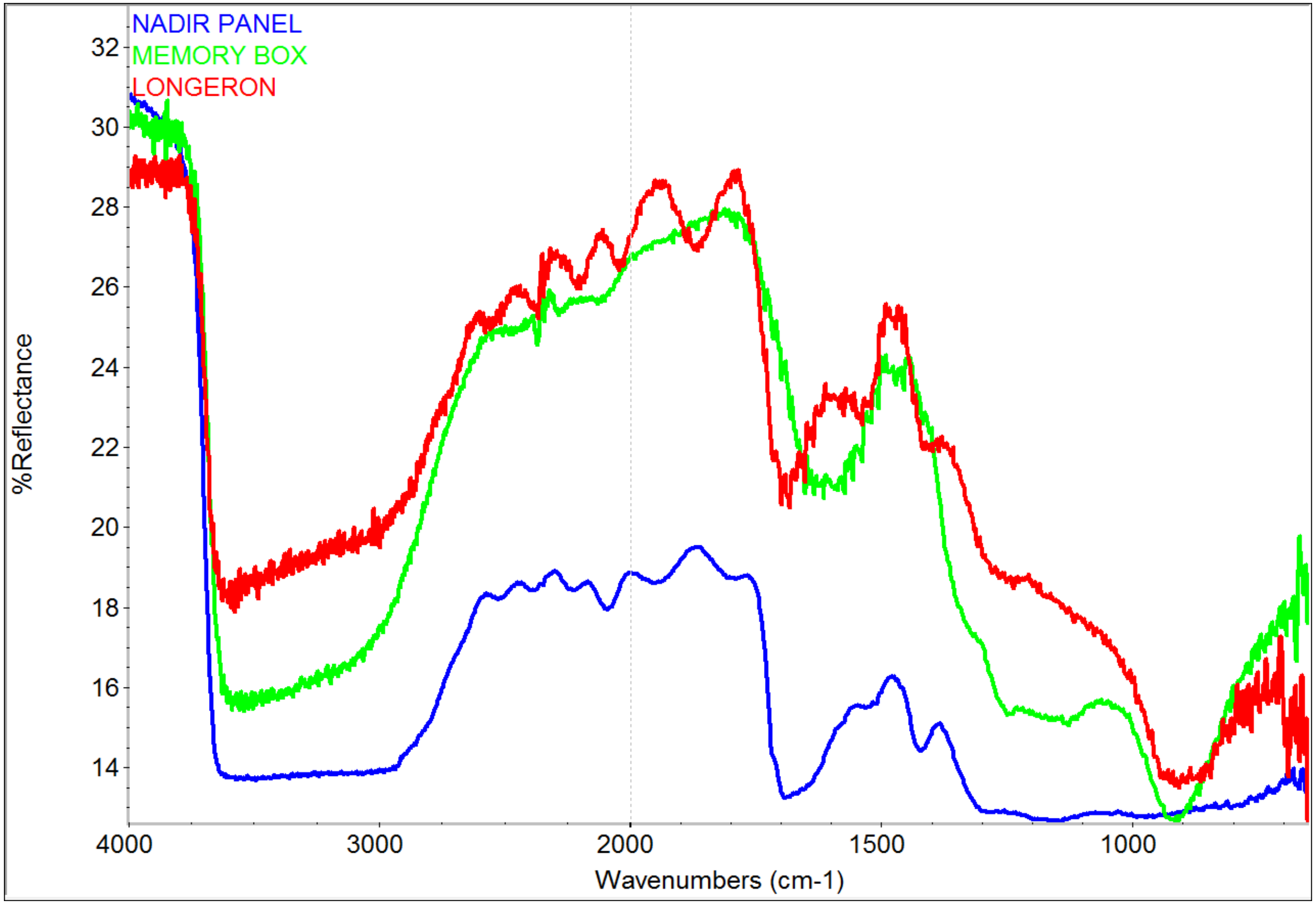
Complex spectrum

Pre Test Spectra: Solar Cell



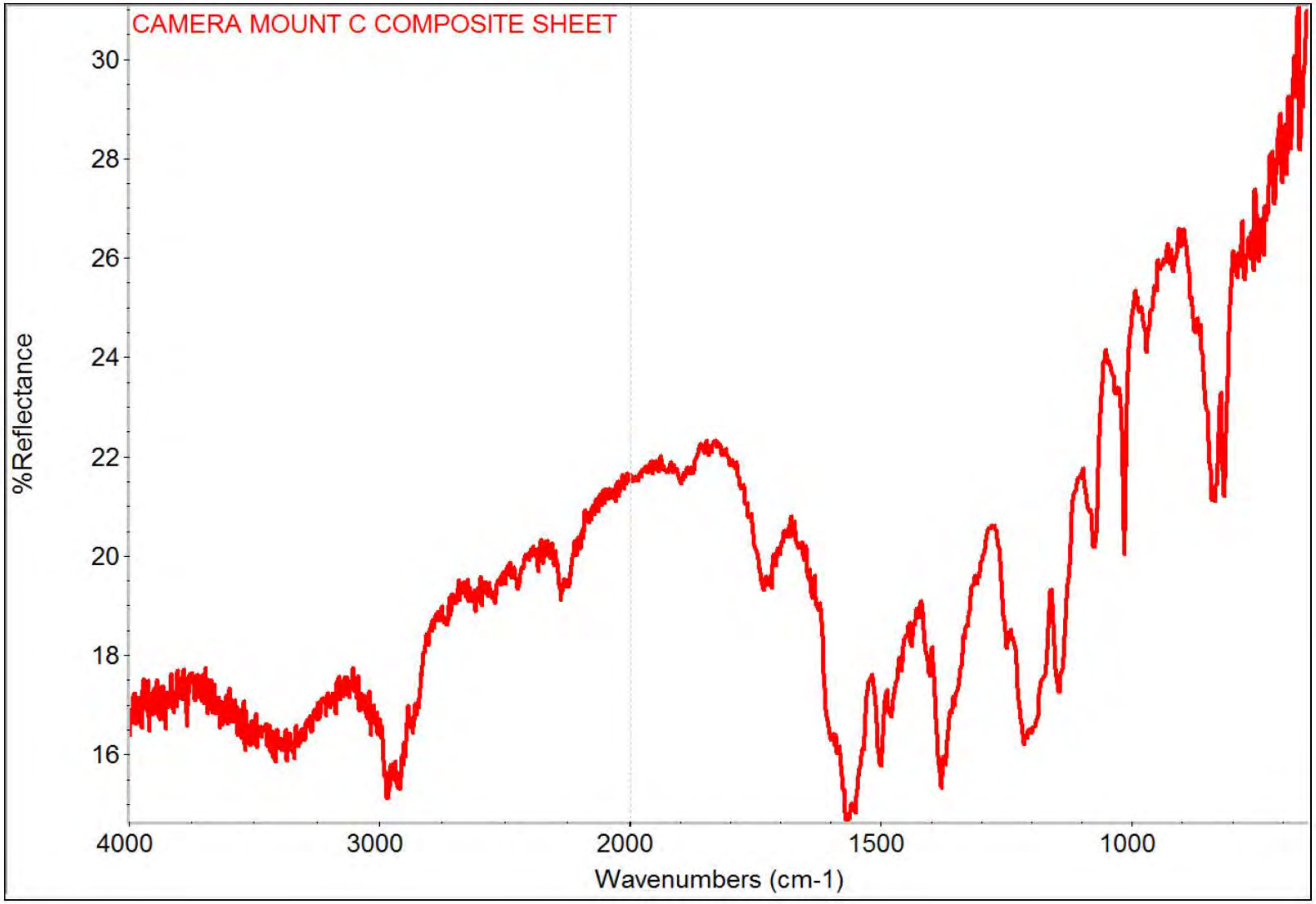
Note silicate feature at 1050 cm^{-1} from coverglass. Thick lines are very closely spaced interference fringes.

Post Test: Anodized aluminum surfaces



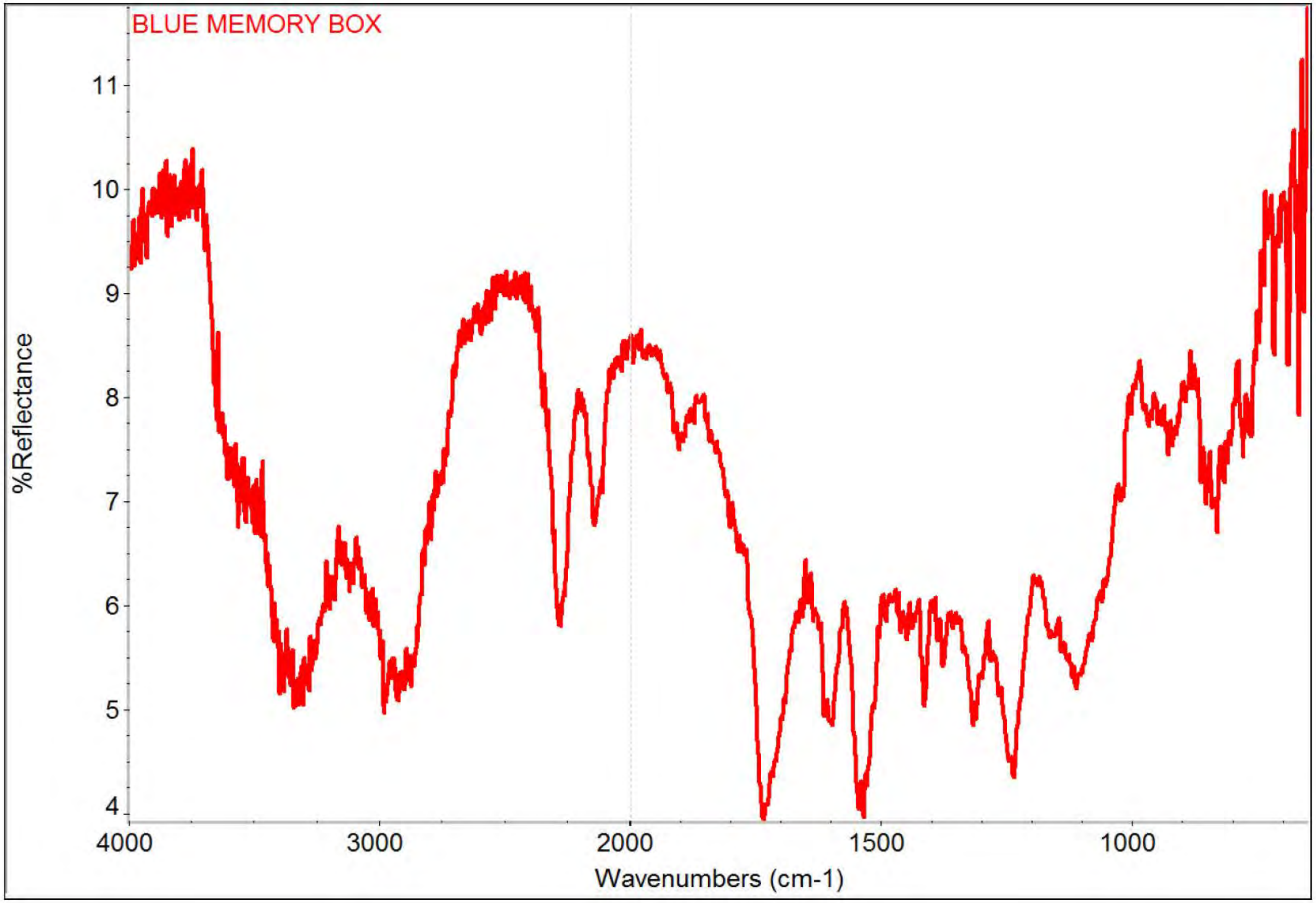
Some components did not show appreciable soft catch contamination. Pretest spectra could not be obtained for direct comparison. Spectra are typical of anodized aluminum.

Post Test: Composite sheet



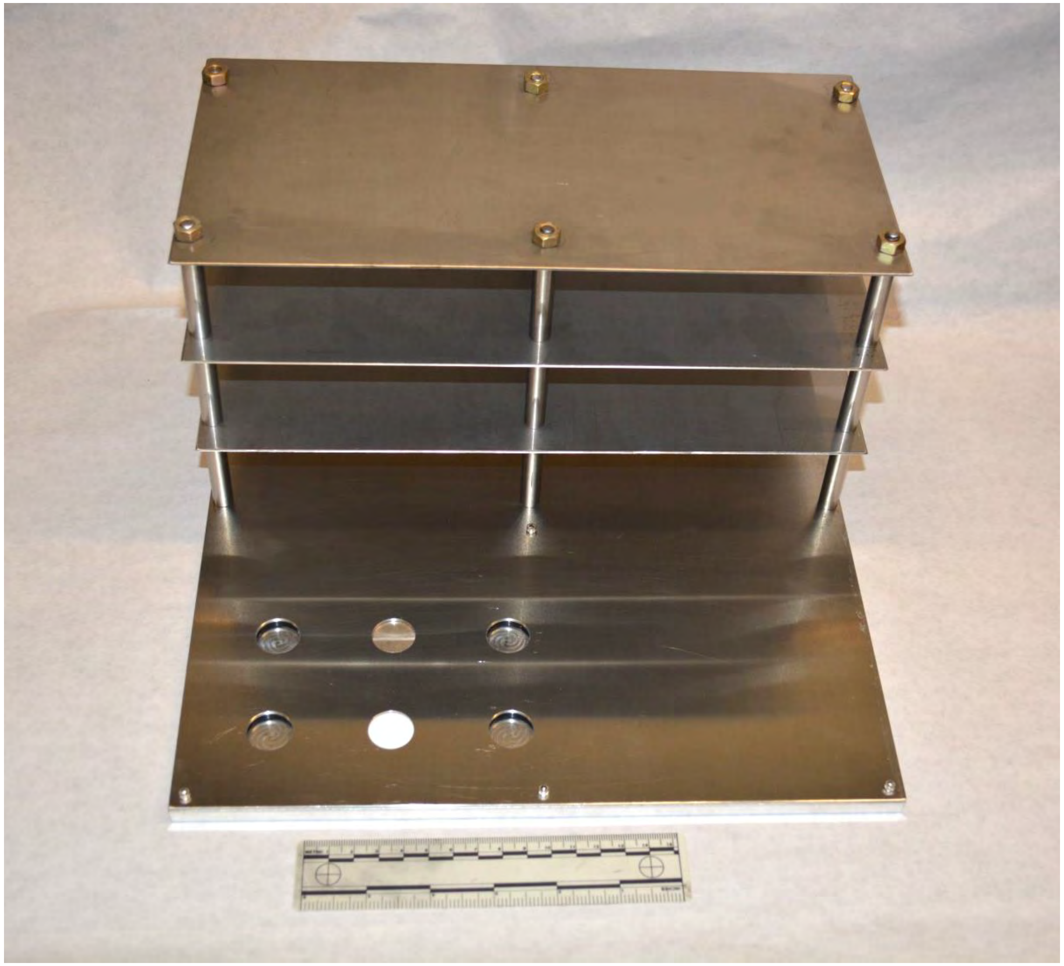
Spectral features from epoxy are evident – could not obtain pretest spectrum.

Post Test: Anodized aluminum surface?



Significant soft catch dust contamination was presnt. Sample had a sparkly appearance.

Witness Plate: Pre Test



Witness Plate Samples:

<u>Direct Exposure</u>

(4) 1” fused silica
(1) 1” Z-93 painted Al
(1) 1” Aluminum
Multi layer insulation (not shown)

<u>Protected Under Whipple Plates</u>

(2) 1” fused silica
(1) 1” Z-93 painted Al
(1) 1” Aluminum
(1) 1” NaCl
(1) Cu sheet
Ge ATR crystal
Solar cell

Witness plates located in same position in chamber as Debris-LV.
~2-3 meters up range of DebriSat.

Witness Plate: Post Test

Witness Plate Samples:

<u>Direct Exposure</u>

(4) 1” fused silica **(D)**
(1) 1” Z-93 painted Al
(1) 1” Aluminum
Multi layer insulation

<u>Protected Under Whipple Plates</u>

(2) 1” fused silica
(1) 1” Z-93 painted Al
(1) 1” Aluminum
(1) 1” NaCl **(D)**
(1) Cu sheet
Ge ATR crystal **(D)**
Solar cell

(D) = destroyed

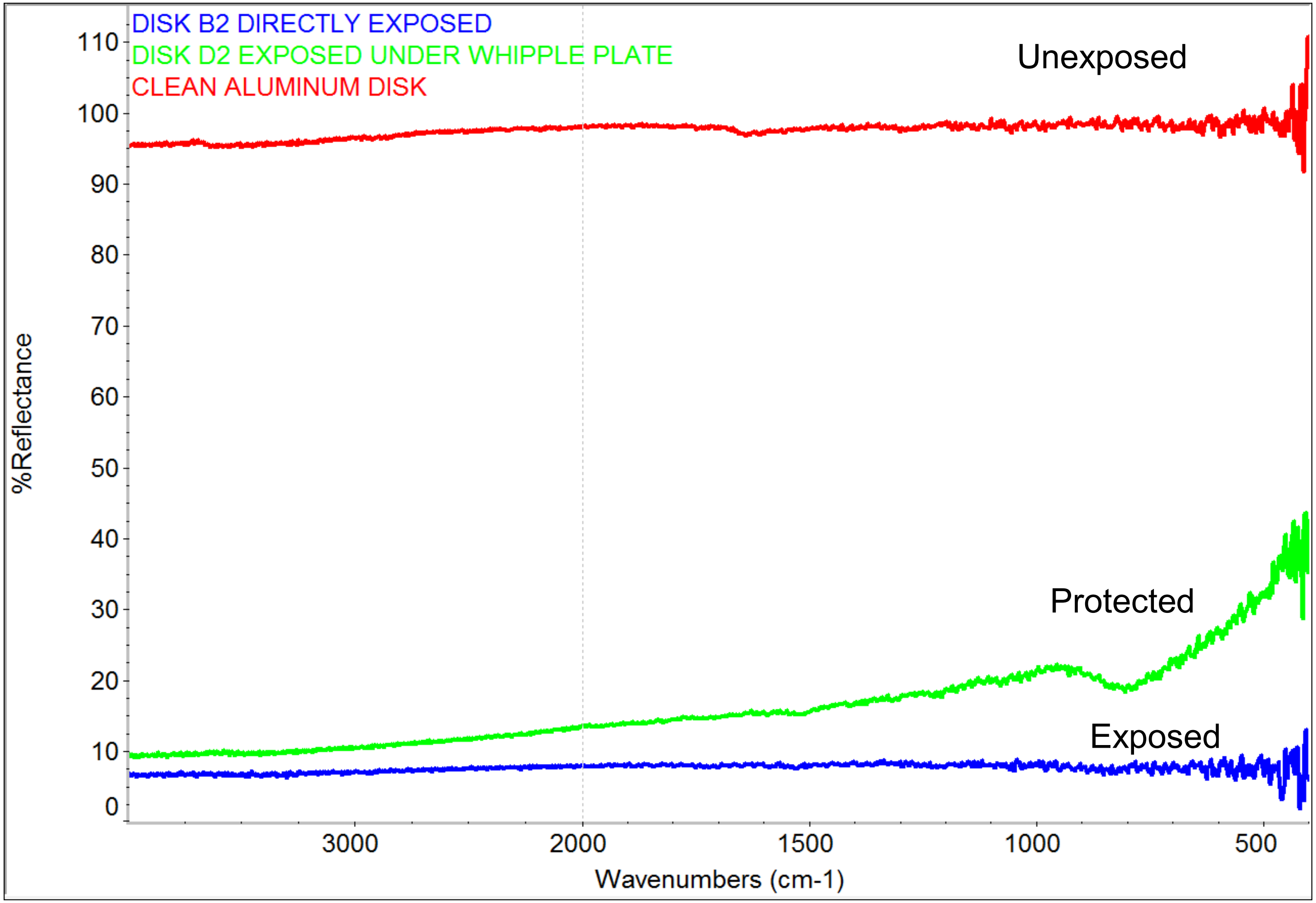
Whipple plate received a significant impact. Many witness plate samples were fractured/destroyed.

Post Test: Aluminum Disks

Significant accumulation of debris, especially soft catch fragments on exposed disk

Aluminum Disks

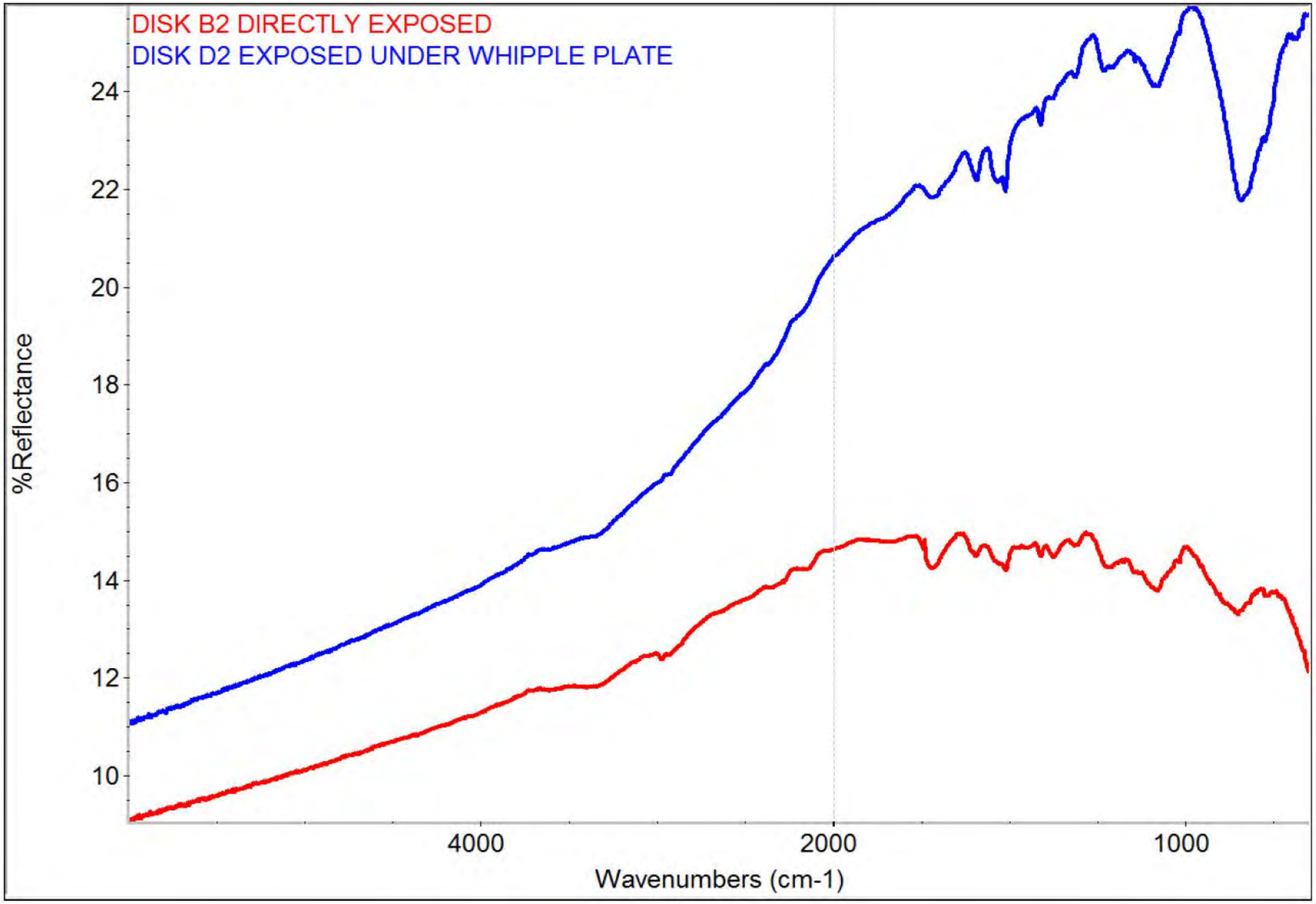
Quantitative Hemispherical Reflectance



Decrease in reflectance from 95% to 5%. Significant darkening.
Note reflectance minimum "oxide" band at 800 cm^{-1}.

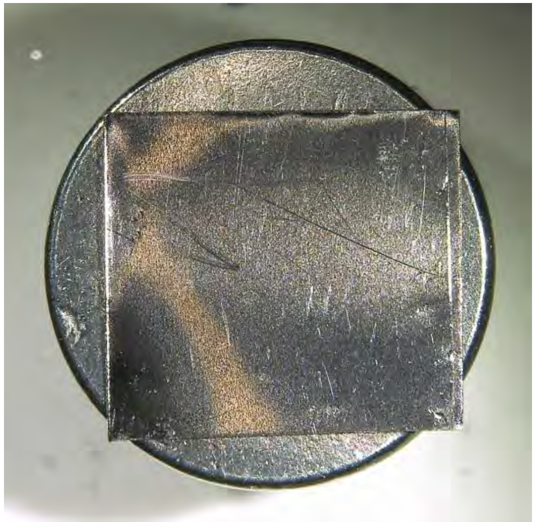
Aluminum Disks

Qualitative Biconical Reflectance



Soft catch contamination is present plus additional “oxide” band at 800 cm^{-1} on sample protected under Whipple plate.

SEM Stubs

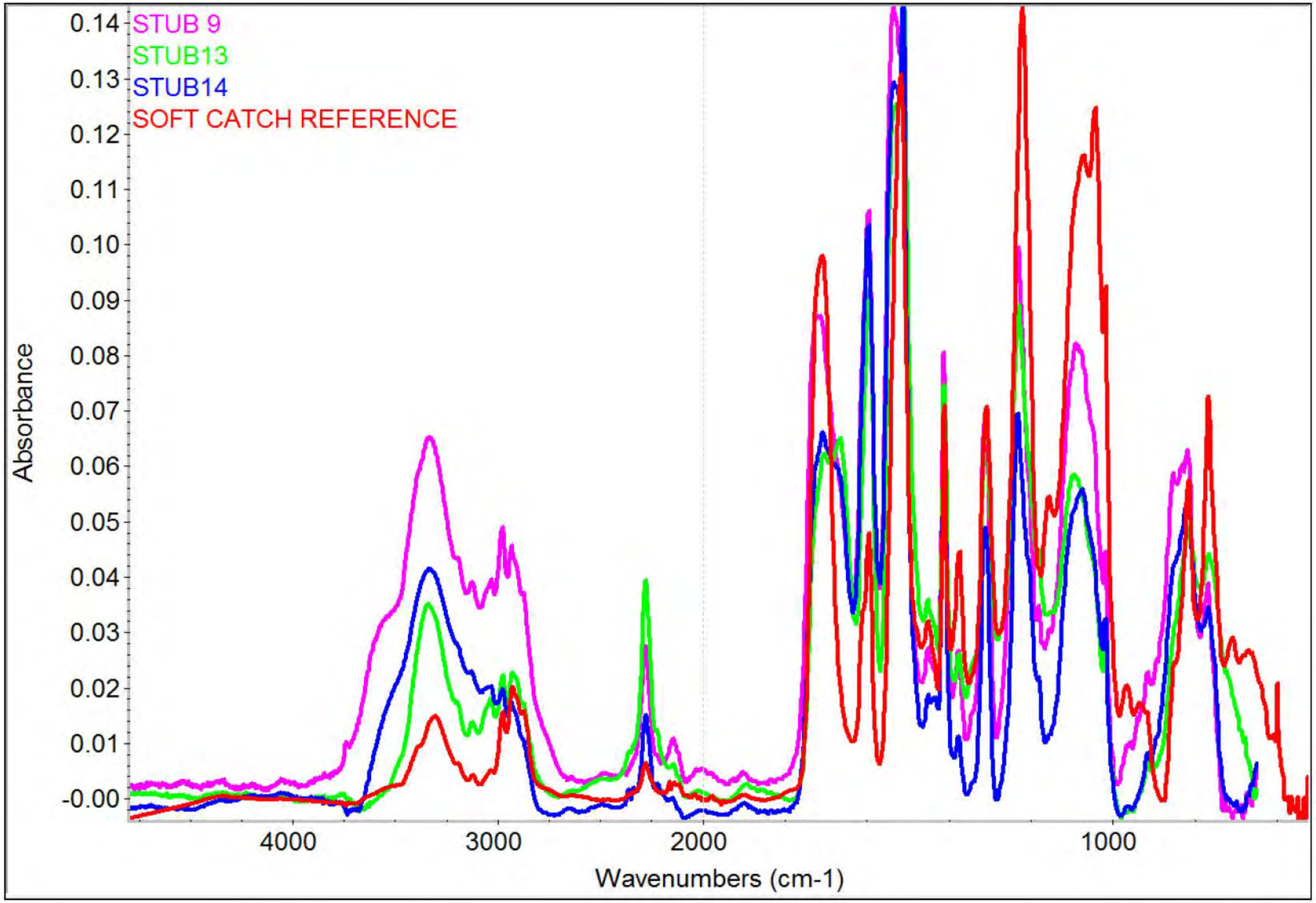


Unexposed | Exposed #13 | Exposed #14

Tantalum sheet on aluminum stub. Note significant darkening of post test stubs

Post Test: SEM Stubs

Biconical Reflectance



Soft catch signature is present on SEM stubs.

Summary

- It was not possible to get clean spectra of hypervelocity impact debris.
- SEM stubs and witness plate assembly were contaminated with soft catch fragments.
  - – SEM stubs also had soft catch film.
  - – Similar to Debris-LV.
- Significant darkening seen on witness plates.
  - Drop from 95% to < 10% reflectance.
  - Greater than in pre preshot – similar to Debris-LV
    - A result of soft catch debris?
    - Highly absorbing disordered graphitic carbon also detected by Raman.
- Pre test spectra not available for internal DebriSat components.
- Some soft catch debris contamination present on DebriSat fragments.
  - – Fewer fragments to examine.
- Additional “oxide” band seen on witness plate samples.
  - – Similar to Debris-LV
- Other laboratory analyses documented:
  - P.M. Adams, Z. R. Lingley, N. Presser and G. Radhakrishnan, DebriSat Laboratory Analyses, The Aerospace Corporation TOR-2015-00876.

Conclusions

- Various materials have spectral features in the LWIR that can be used to identify them.
  - Anodized aluminum, solar cells, multilayer insulation, paint.
- Pre Preshot test did not utilize soft catch foam and hence had no contamination.
  - Of the three tests it represents the best example of hypervelocity impact debris spectral signatures.
  - Spectra showed silicate and borate features from melted/vaporized E-glass from penetrated bumper shields.
  - Silicate feature shifted as a result of composition changes.
  - Darkening to < 25% reflectance was observed on many surfaces after hypervelocity impact.
- Soft catch contamination was prevalent on Debris-LV and DebriSat fragments.
  - Soft catch **film** and fragments also present on SEM stubs.
    - Film condensed from vaporized foam.
  - Spectra from soft catch made it difficult to evaluate true hypervelocity impact spectral signature.

Conclusions (cont.)

- Debris-LV samples did have an extra feature at 800 cm^{-1} possibly due to a form of aluminum oxide.
    - From the LV aluminum tank or projectile?
- Aluminum oxide not as evident on DebriSat fragments but fewer samples to examine
    - Less aluminum in the DebriSat structure.
    - Was observed in witness plate samples.
- The formation of an oxide would not occur on orbit unless there was a source of oxygen in the impacted materials.
- Darkening to < 10% reflectance was observed on Debris-LV and DebriSat witness plate surfaces after hypervelocity impact.
    - This was greater than on pre Preshot (to 20-25%).
    - Possibly due to extra soft catch contamination.
    - Disordered graphic carbon also detected on Debris-LV and DebriSat
        - No spectral features but highly absorbing – produced black “sooty” appearance?

Appendix 1
Laboratory Instrumentation

Fourier Transform Infrared (FTIR) Spectrometer

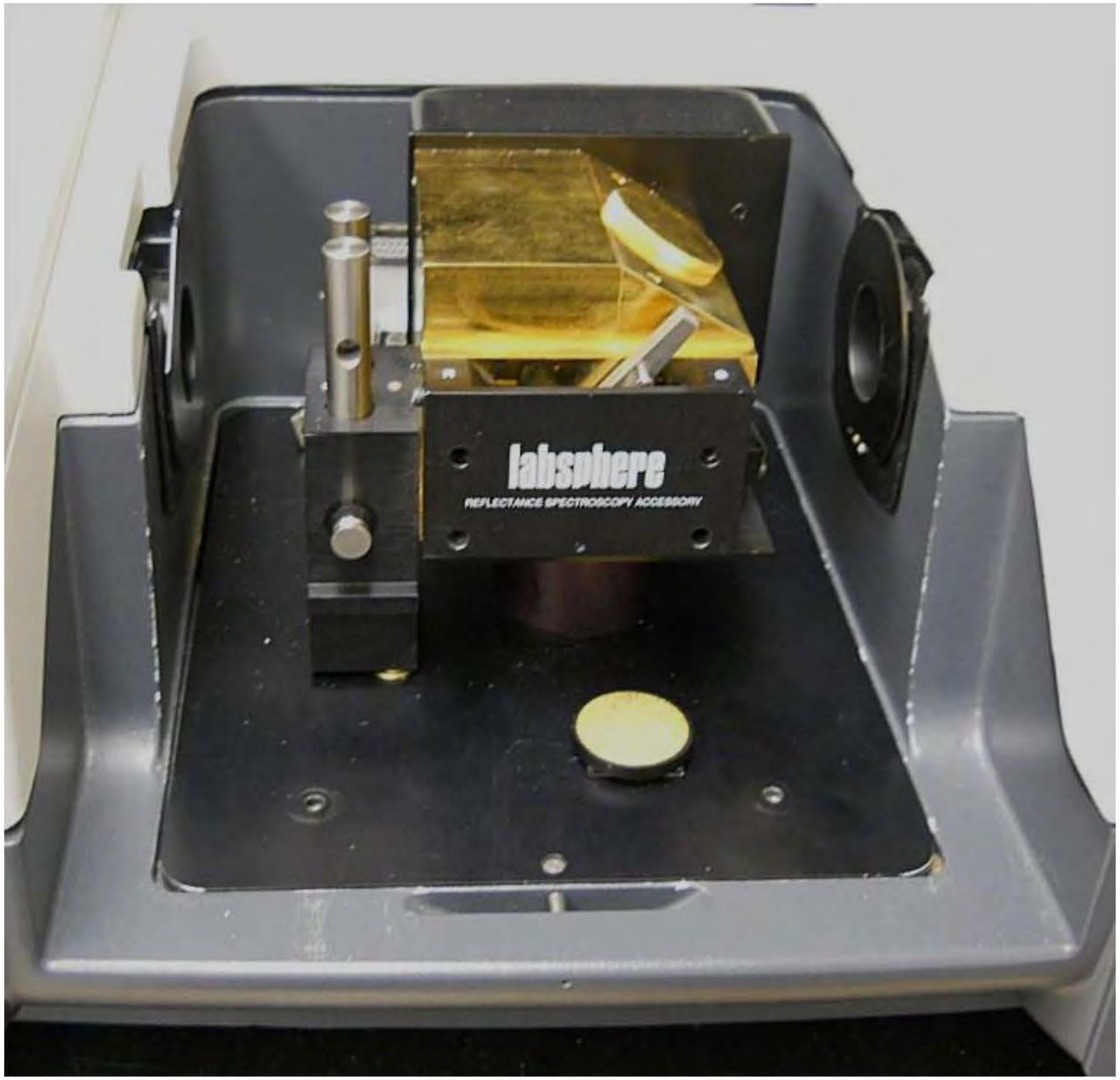
Thermo-Nicolet 6700 FTIR and Continuum Microscope

Labsphere integrating sphere in sample compartment at right

Thermo-Nicolet Model 6700 FTIR Spectrometer

- Sources:
  - Globar (IR), Tungsten (Visible).
- Beam Splitters:
  - Extended range KBr/Ge (11,000 - 400 cm^{-1}).
  - Solid substrate (700 – 50 cm^{-1}).
- Resolution: to 0.125 cm^{-1}
- Detectors:
  - DTGS-KBr (6,000-400 cm^{-1}).
  - Mercury cadmium telluride (MCT) (11,000-650 cm^{-1}).
  - PbSe (11,000-2000 cm^{-1}).
  - DTGS-PE (700 – 50 cm^{-1}).
- Typical configuration for biconical and hemispherical diffuse reflectance measurements:
  - Globar source, extended range KBr beam splitter, MCT detector(biconical), DTGS detector (hemispherical).
  - 4000-650 cm^{-1} (2.5 – 15.4 microns), 4 cm^{-1} resolution.

Hemispherical Reflectance

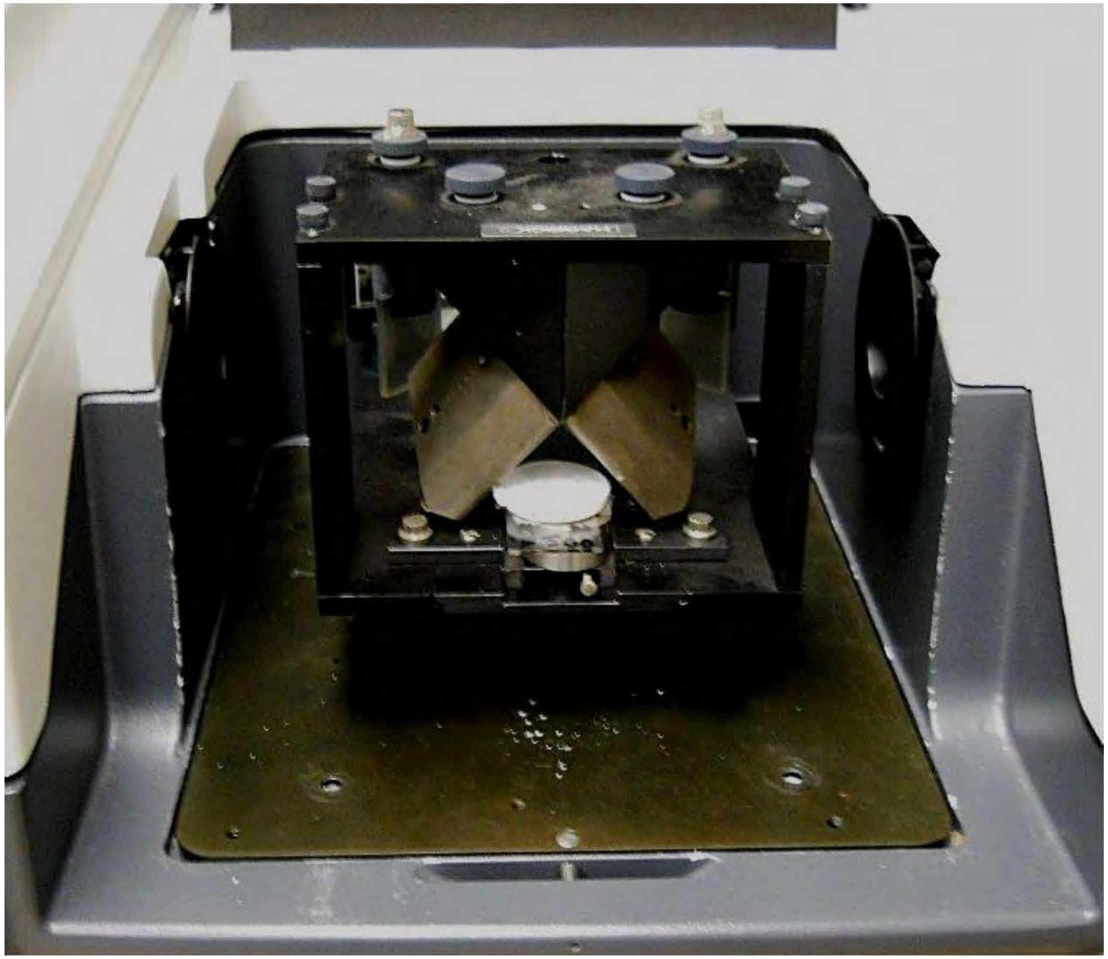


Labsphere Integrating Sphere

Hemispherical Reflectance

- Labsphere 4” dia “in bench” integrating sphere lined with Infragold.
- Dedicated DTGS detector.
- Spot size 5-7 mm.
- Maximum sample size: 5.5” x 9” x 0.6” (to 2”).
- Minimum sample size: 0.90” dia.
- Possible to exclude the specular component.
- QUANTITATIVE reflectance measurements - but poor signal to noise (S/N) as a result of weak signal and low sensitivity DTGS detector.
- Relatively insensitive to surface topography.
- Typical scan parameters:
    - 4000 – 400 cm^{-1} (2.5 – 25 microns).
    - 4 cm^{-1} resolution
    - Scan time (500 - 1000 scans) 30-60 minutes.
    - 12-14 hour background scan improves S/N.

Biconical Reflectance



Harrick Scientific “Praying Mantis” Diffuse Reflectance Accessory

Biconical Reflectance

- Harrick Scientific "Praying Mantis" Diffuse Reflectance Accessory.
- Spot size 1-2 mm. Parabolic mirror focuses beam on sample.
- QUALITATIVE reflectance measurements ONLY.
    - Very sensitive to sample height/topography because of focused beam.
    - Reproduces spectral shape but not intensity.
    - Excellent signal to noise in a short period of time.
    - Sensitive to sample inhomogeneity.
- Maximum sample size: 0.75" (high) x 1" x 3".
- Typical scans:
    - 4000 – 650 cm^{-1} (2.5 – 15.4 microns).
    - 4 cm^{-1} resolution
    - Scan time (150 scans) 1-2 minutes.

Agilent Exoscan Portable FTIR

(Imaging Spectroscopy Department)

Agilent Exoscan Biconical Reflectance

- Agilent(A2) Exoscan Portable FTIR.
- Parabolic mirror focuses beam on sample.
- Diffuse reflectance head uses diffuse gold as reference.
- Spot size about 5 mm.
- QUALITATIVE reflectance measurements ONLY.
  - Generally can only analyze relatively flat samples.
  - Must make contact with sample.
  - Reproduces spectral shape for material identification.
  - Reasonable signal to noise in a short period of time.
- Typical scans:
  - 4000 – 650 cm^{-1} (2.5 – 15.4 microns).
  - 4 cm^{-1} resolution
  - Scan time 30 seconds.

Appendix 2

Technical Reports Addendum Asset Summary

AEROSPACE

TRAAS ID #: 201501201218211482O

Report Name: FTIR Analyses of Hypervelocity Impact Deposits: DebriSat Tests

Aerospace Report Number: TOR-2015-00941

Start Date of Test: 2014-03-01 Created By: 14820 Adams, Paul M JO: 850672

End Date of Test: 2015-01-01 First Aerospace Author / PI: 14820 Adams, Paul M

Program: DebriSat

Description:

Keywords:

Asset: ABW501 Manufacturer: THERMO-NICOLET Model: 6700 Usage Start Date: 2014-03-01 Usage End Date: 2015-01-01 Asset Comment:

Date:	Calibration Due Date:	Comment:	Certificate Number:
2013-01-31	2014-03-30	TMT-NORMAL	03b8d9f80c759543aa3684c5737e5c48
2014-03-17	2015-08-16	TMT-NORMAL	c0ad25e310e49243ae8a043b67c2c0f1

Asset: ACW683 Manufacturer: AGILENT Model: 4100 EXOSCAN FTIR Usage Start Date: 2014-03-01 Usage End Date: 2015-01-01 Asset Comment:

Date:	Calibration Due Date:	Comment:	Certificate Number:
2013-02-22	2014-03-16	TMT-NORMAL	46f0ef7486d11c44b5ff577844d47966
2014-03-05	2015-07-05	TMT-NORMAL	04fcd18413cf074b91d37e955d3b2279

*Support and Auxiliary Equipment are not calibrated.

Tue Jan 20 12:24:53 PST 2015 Page 1 of 1

AEROSPACE REPORT NO.
TOR-2015-00941

FTIR Analyses of Hypervelocity Impact Deposits: DebriSat Tests

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GROUP

SC2478

External Distribution

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REPORT NO. TOR-2015-00941	PUBLICATION DATE March 27, 2015	SECURITY CLASSIFICATION UNCLASSIFIED

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